DRIVETRAIN

1 Introduction

Vehicle production in Japan in 2021 was 7,846,958 units, down 2.7% from the previous year and the first time in 45 years since 1976 that production fell below 7.9 million vehicles. Production has now fallen on a year-by-year basis for three consecutive years, mainly due to a global shortage of semiconductors and disruptions to the parts supply chain as the COVID-19 pandemic spread throughout Southeast Asia. Despite these factors, the Japanese automotive industry is strengthening its initiatives toward electrification in response to the government's Green Growth Strategy toward achieving carbon neutrality, which was announced in 2020 and has spurred development into battery electric vehicles (BEVs) and a range of other electrified powertrains. Running parallel to this trend, the performance of conventional drivetrain units is being steadily enhanced, with hardware and controls being improved to realize both environmental and driving performance. This article summarizes the latest drivetrains released in the automotive industry in 2021, and also takes a look at the technological trends paving the way for next-generation drivetrains.

2 Manual Transmission (MT) Trends

Front-Engine Front-Wheel Drive 5-Speed MT for the Daihatsu Rocky (Indonesia)

In April 2021, PT Astra Daihatsu Motor launched the Rocky, which is equipped with a new front-engine front-wheel drive 5-speed MT developed by Akashi-Kikai Industry Co., Ltd. and Daihatsu Motor Co., Ltd. (Fig. 1). This transmission adopts a smaller gear spline module that enables a shorter shift stroke. This configuration raises the permitted input torque by increasing the face width of the helical gears and enabling a low gear suitable for the model's large SUV tires, while maintaining the dimensions (length and center distance among axes) of the previous model. The shift and select mechanism (Fig. 2) includes shift forks for the first and second and third and fourth gears on the shift and selector shaft, thereby reducing the weight and number of transmission parts. The adoption of a shaft sliding action and reducing

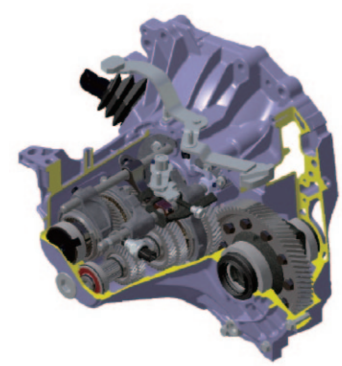

Fig. 1 Appearance of Daihatsu Front-Engine Front-Wheel Drive 5-Speed MT

Fig. 2 Shift and Select Mechanism

the clearance between sliding parts and sliding resistance during shifting realizes a smooth and precise sensation when the driver changes gears.

3 Automatic Transmission (AT) Trends

Front-Engine Rear-Wheel Drive 10-Speed AT for the Toyota Land Cruiser 300

The new front-engine, rear-wheel drive 10-speed AT mounted in the new Land Cruiser 500 was developed both for off-road performance and to enhance the rough

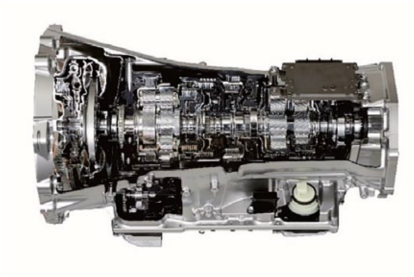

Fig. 3 Front-Engine Rear-Wheel Drive 10-Speed AT for the Toyota Land Cruiser 300

road performance of the Land Cruiser. This transmission has an even wider gear range than the previous transmission, and realizes an impressive balance between driving performance, excellent fuel economy, and low noise (Fig. 3).

The 1st gear ratio is 3% lower than the previous transmission and cross ratios were set for the 1st to 3rd gears. This enables full utilization of the available engine power and helps to enhance standing start performance as well as performance over rocky and sandy surfaces. Additionally, the top gear ratio is 9.4% higher than the previous transmission, which enables highly efficient engine operation at all times and lowers the engine speed during high-speed cruising, helping realize excellent fuel economy and low noise.

In addition, this Land Cruiser also features a newly developed torque converter with a greatly expanded lock-up area compared to the previous 8-speed automatic transmission. This was achieved by adopting a multi-plate lock-up clutch with excellent oil pressure response (Fig. 4) and a new dynamic damper. These measures greatly expand the lock-up area to even lower vehicle speeds and larger accelerator pedal strokes, covering virtually all areas apart from launch and helping to realize both a more direct response to accelerator operations and lower fuel consumption. In addition, to reduce drive-train vibration caused by torque fluctuations when the lock-up area is expanded, an integrated structure that absorbs the backlash between the middle planetary carrier and C-4 drum spline was adopted, and a new backlash stopper was developed that uses the middle planetary carrier as a mass damper.

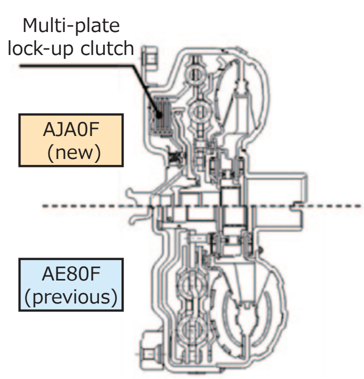

Fig. 4 Cross-Section of Newly Torque Converter

4 Continuously Variable Transmission (CVT) Trends

4. 1. Jatco CVT-X

The newly developed Jatco CVT-X, which was installed on the Nissan Qashqai that was launched in Europe in June 2021, helps to realize both excellent fuel economy and enjoyable driving performance in combination with a downsized turbocharged engine. Its 8.2 ratio coverage combined with a high-performance hydraulic system and lock-up mechanism reduce energy loss by approximately 30%, which makes a major contribution to the fuel efficiency and driving performance of the vehicle.

In addition, the adoption of a short-pitch chain reduces the winding diameter while increasing the diameter of the chain winding up to around the outermost pulley diameter. These measures enable the 8.2 ratio coverage with a distance between pulley axes of 180 mm.

The hydraulic system features the Twin Oil Pump system that combines a mechanical oil pump, which is constantly driven by the engine, and an electrical oil pump that operates when necessary. This system generates the required oil pressure without any waste. The mechanical pump is used by itself when driving in urban traffic. The electrical oil pump operates in scenarios requiring larger oil flows for faster shifting, when the engine start-stop system is activated, and when the vehicle is coasting to a stop. This allows the size of the mechanical pump to be greatly reduced and lowers the energy required to generate the necessary oil pressure.

A multi-plate clutch was adopted for the torque converter lock-up mechanism, which expands the slip control when the vehicle moves off up to larger throttle opening regions. Slip control performance was also improved by shortening the dedicated oil passages for the control pressure and reducing the volume of the hydraulic pressure chamber. These measures result in lower

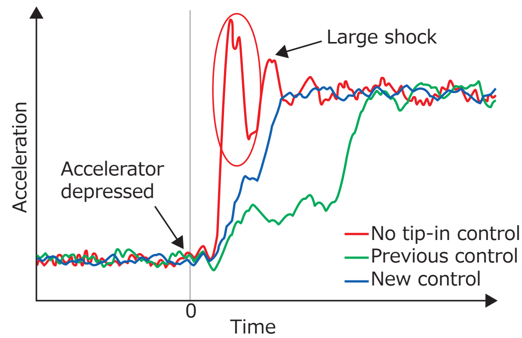

Fig. 5 Comparison of Acceleration Response Due to Differences in Tip-In Control Methods

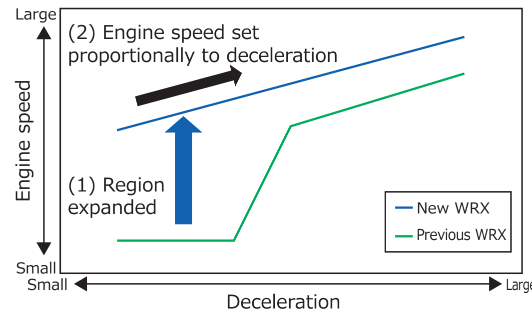

Fig. 7 Comparison of Downshift Engine Speed during Braking

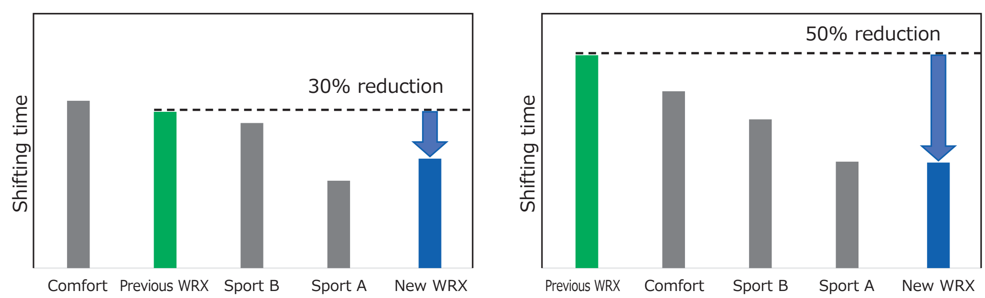

Fig. 6 Comparison of Up-Shift and Down-Shift Times

energy loss and improved driving performance.

4. 2. Subaru WRX S4 Lineartronic

The new WRX S4 that was launched in February 2022 pairs Subaru's iconic and extremely fun-to-drive 2.4-liter direct-injection turbocharged boxer engine with a CVT that incorporates a sporty shift control to enhance dynamic feel.

During tip-in, this control coordinates with the ignition timing control to reduce shock and improve response when the accelerator is depressed (Fig. 5). In addition, during shifting, the control coordinates with the throttle, ignition timing, and cylinder cut-off controls to cancel out the inertial mass from the engine to the primary pulley. As a result, upshifts are 30% faster and downshifts are 50% faster than the previous transmission, realizing snappy shifts equivalent to that of a dual clutch transmission (DCT, Fig. 6).

At the same time, the adaptive control region was expanded. The previous transmission activated adaptive control in high deceleration regions. The new sporty shift control improves the quality of shifting so that the adaptive control can be activated from lower deceleration regions. This enables downshift control proportional to the deceleration, making the engine speed more predictable (Fig. 7).

Fig. 8 Cut Model of Daihatsu FR-CVT

4. 3. Front-Engine, Rear-Wheel Drive CVT for Daihatsu Hijet and Atrai

In December 2021, Daihatsu launched completely redesigned versions of the Hijet Cargo and Atrai as well as a partially redesigned Hijet Truck. The Hijet Cargo and Atrai are the first commercial vehicles to adopt the brand new Daihatsu New Global Architecture (DNGA) platform, and the Hijet Truck features an updated powertrain. These vehicles are equipped with a front engine, rear wheel-drive CVT (FR-CVT) developed by Daihatsu (Fig. 8).

The FR-CVT incorporates a metal belt CVT with an input reduction gear to improve vehicle fuel economy and an output reduction gear. The output reduction gear optimizes the gear CVT ratio to prevent the characteristic abnormal beating noise of a front engine, rear wheel-

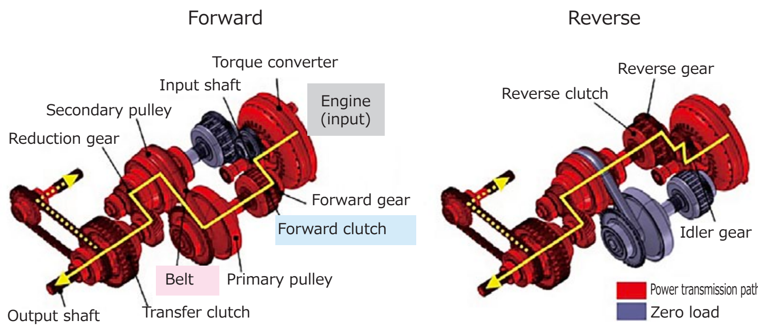

Fig. 9 Power Flows of Daihatsu FR-CVT

drive vehicle and enable full-region lock-up.

An electronically controlled four-wheel drive (4WD) system with three selectable modes (2WD, 4WD lock, and automatic 4WD) was also adopted to improve the product appeal of the vehicle. The electronically controlled coupling is built into the CVT and the CVT oil pump is used to drive the hydraulic system to realize a compact structure at a reasonable cost.

Figure 9 shows the torque flows of the FR-CVT. Since commercial vehicles are used in a wide variety of environments, the FR-CVT uses a belt protection system when driving forward and a gear drive in reverse to ensure belt reliability. The belt protection system when driving forward controls the hydraulic pressure to ensure the following relationship: input torque from engine < forward clutch torque capacity < belt torque capacity. When excess input is delivered from the tires, the clutch acts as a fuse to protect the belt.

A wide range of size-reduction technologies are also used to ensure spacious cargo room. In a mini commercial vehicle with a front-engine, rear-wheel drive layout, the CVT has to be installed in the underbody, which places severe restrictions on its height. The FR-CVT realizes the same height and length as a 4-speed AT due to its parallel forward/reverse shaft layout with the forward and reverse clutch shafts located separately on either side of the input shaft, and the valve body and strainer located on the same plane.

5 Drive Systems for Hybrid Vehicles

e-SMART HYBRID System for Daihatsu Rocky

e-SMART HYBRID is a series hybrid system that uses the engine to generate electricity, which is then utilized for motor drive. A simple mechanism that uses a newly developed 1.2-liter engine exclusively for generating electricity results in an ideal compact hybrid system for small cars. In addition to highly responsive acceleration and extremely quiet performance provided by the 100%-electric motor drive, optimal control of electricity generation, charging, and discharging realizes excellent fuel economy at an affordable price.

Fig. 10 Appearance of HV transaxle

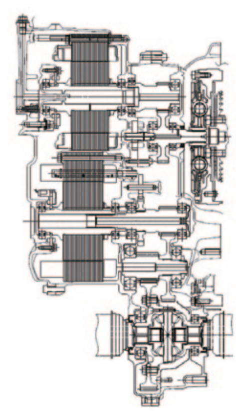

Fig. 11 Main cross-section of HV transaxle

Figure 10 shows the appearance of the hybrid vehicle (HV) transaxle and Fig. 11 shows its main cross-section. The HV transaxle consists of a motor generator (MG), which charges the HEV battery and supplies drive power, and drive motors in a multi-shaft layout that shortens the length of the transaxle. The gear train in this system functions to transmit the power from the drive motors to the output shaft. It features a speed reduction device

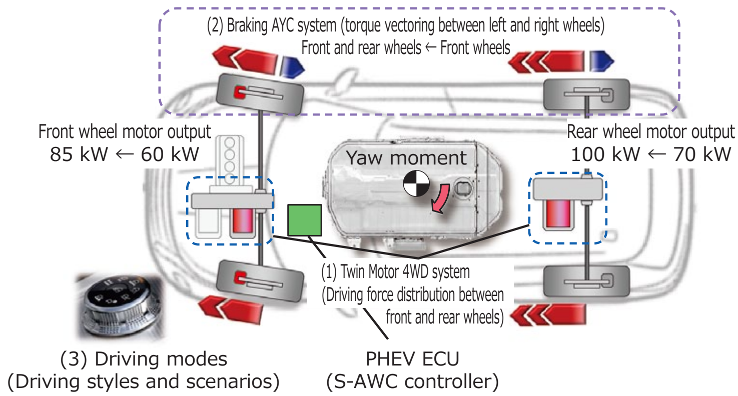

Fig. 12 Outline of New Outlander PHEV S-AWC System

Table 1 Driving Mode Control Concept

	Mode	Control concept	Typical driving scenario
Driving style	POWER	Provide the overwhelming acceleration feeling typical of an electrified vehicle.	Overtaking on a highway
Driving style	ECO	Provide environmentally friendly and economical driving performance.	City streets
Driving style / Driving scenario	NORMAL	Provide the reassurance of an SUV under various road environments.	Normal driving
Driving scenario	TARMAC	Realize agile and fun-to-drive performance on paved roads.	Mountainous roads
Driving scenario	GRAVEL	Provide powerful and stable driving performance on unpaved roads.	Unpaved roads Wet paved roads
Driving scenario	SNOW	Provide surefooted and highly confident performance on icy and snowy roads.	Icy and snowy roads
Driving scenario	MUD	Provide confident and powerful driving performance capable of handling mud and deep snow.	Mud roads Roads covered in deep snow

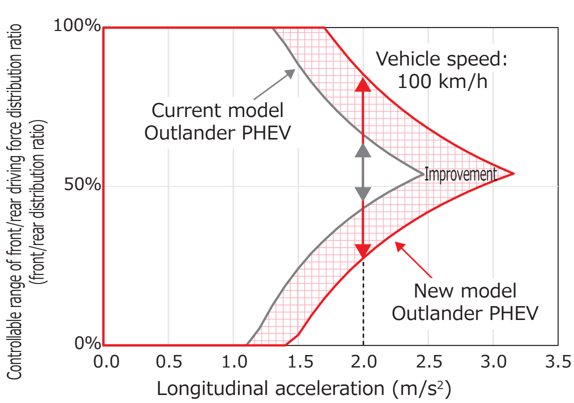

Fig. 13 Control Range of Front/Rear Driving Force Distribution Ratio

consisting of a motor reduction gear, pair of counter gears, and pair of final gears, and a differential mechanism. The number of component gears in the gear train was minimized by optimizing the position of the gear train, resulting in a compact system with excellent power performance. In addition, noise was reduced by applying high-precision machining to the gear faces. Better fuel economy was also achieved by enabling drive with the final driven gear to lower the height of the oil surface and by adopting dry sump lubrication to reduce the oil mixing loss.

6 4WD Device Trends

Super-All Wheel Control (S-AWC) for Mitsubishi Outlander PHEV

First introduced in 2013, the S-AWC integrated vehicle dynamics control system installed on the Outlander PHEV functions to improve traction control and handling via the Twin Motor 4WD system that distributes driving force between the front and rear wheels and the Active Yaw Control (AYC) braking system that performs torque vectoring between the left and right wheels.

Under the concepts of "stronger" and "faster", the new Outlander PHEV is improved in the following three ways to realize even safer, confident, and comfortable driving performance in any weather and on any road surface (Fig. 12).

(1) Higher maximum power for the front and rear wheel motors

The maximum power of the front and rear wheel motors was increased to 85 and 100 kW, respectively, In addition to powerful driving performance, this expands the control range of the front/rear driving force distribution ratio in the middle to high vehicle speed range, resulting in better handling (Fig. 13).

(2) Enhanced braking AYC

The developed system applies braking AYC to the two wheels at the front and rear, thereby improving cornering performance by balancing how the front and rear tire capabilities are utilized.

(3) Adoption of driving modes

The driver can select between seven driving modes in accordance with the desired driving style or scenario (Table 1). These modes adjust the control amounts of front/rear wheel driving force distribution, accelerator response, ATC, electric power steering, traction control, and Active Stability Control (ASC) based on the NORMAL mode to realize even safer, confident, and comfortable driving performance suitable for various driving scenarios and styles.

7 Drivetrain Research Trends

To help achieve carbon neutrality by 2050, conventional and electrified components must be made even more efficient, smaller, and lighter. Other requirements include reducing carbon dioxide emissions during manufacturing, as well as paying even greater attention to the concepts of rebuilding, reusing, and recycling. For these reasons, it will be necessary to focus on fundamental research efforts centered on materials. In addition, autonomous driving and other core aspects of the new mobility society of the future will also depend on the development of cooperative technologies for power transmission, shifting, and vehicle controls. This will require a wide range of research and development centered on electrified components.