DIESEL ENGINES

1 Introduction

The necessity for urgent measures to help reduce greenhouse gas (GHG) emissions has been recognized on a global scale. Many developed nations including Japan have made major changes to their policies with the aim of achieving carbon neutrality. As the need to reduce the carbon load of vehicles becomes even more pressing, Europe has continued to lead the way in emphasizing the necessity and importance of minimizing GHG emissions and has already initiated concrete policies toward this end. Specific measures include reducing vehicle CO_2 emissions by the adoption of policies to adopt zero emission vehicles (ZEVs). Many countries and regions, including Europe, the U.S., and Japan, have laid out roadmaps for achieving carbon neutrality that state specific national numerical targets for reducing CO_2 emissions. In response, automakers are accelerating vehicle electrification plans and other carbon-neutral initiatives.

Despite the increasingly active debate about achieving carbon neutrality, 2021 did not see the introduction of any more stringent regulations or standards surrounding emissions, fuel economy, or CO_2. However, continuous discussions were held in Europe about the adoption of Euro 7/VII. On a relevant note, Japan has already introduced real driving emissions (RDE) standards, and the U.S. has decided to adopt more stringent GHG and NO_x standards within the next two to three years.

This article mainly describes the characteristics and summarizes the new diesel engines announced or launched in 2021.

2 Trends inside Japan

2. 1. Overview

(1) Diesel Engines for Passenger Vehicles

Toyota Motor Corporation launched the new 3.3-liter F33A-FVT engine for SUVs.

(2) Diesel Engines for Commercial Vehicles

No new engines were announced or launched in 2021.

2. 2. New Engine Characteristics (Table 1)

(1) Toyota F33A-FVT (Fig. 1)

The structure of each part of the engine, such as the piston cavity, intake ports, and injectors was optimized to realize an engine that combines excellent fuel economy with impressive power and torque. The adoption of a variable nozzle two-way twin-turbocharger helps to realize powerful acceleration at low speeds by taking advantage of the rapid response provided by a single turbocharger, while ensuring smooth acceleration at high speeds due to the large intake airflow provided by a twin-turbocharger.

3 Trends outside Japan

3. 1. Overview

(1) Diesel Engines for Passenger Vehicles

Although announced in 2020, Audi launched its 3.0-liter V6 TDI engine for SUVs and Jaguar Land Rover (JLR) launched its new 3.0-liter D250/D300/D350 engines, also for SUVs. These engines were mounted in combination with mild hybrid systems. No new engines were announced in 2021.

(2) Diesel Engines for Commercial Vehicles

In Europe and the U.S., several refined versions of existing engines for heavy-duty vehicles were announced or launched to comply with CO_2 and GHG regulations and to reduce the total cost of ownership (TCO) of commercial vehicles via lower fuel consumption.

3. 2. New Engine Characteristics (Table 1)

(1) Audi 3.0-Liter V6 TDI (Fig. 2)

This engine adopts forged steel pistons to reduce heat loss from the combustion chamber while suppressing the increase in weight compared to aluminum pistons. These pistons also have a stepped recess that increases the speed of combustion and improves combustion characteristics. The solenoid type injectors incorporate piezo

Table 1 New Engine Specifications

Region	Year announced/launched	Application	Manufacturer	Engine model	Cylinder arrangement	Bore diameter × stroke (mm)	Total displacement (cc)	Compression ratio	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Characteristics
Japan	2021	Passenger vehicles	Toyota	F33A-FTV	V6	86.0 × 96.0	3,345	—	227/4,000	700/1,600-2,600	Two-way twin-turbocharger, electronically controlled fan coupling, urea SCR
Outside Japan	2020	Passenger vehicles	Audi	—	V6	83.0 × 91.4	2,967	16.3	251/3,800-3,950	700/1,750-3,250	Mild hybrid, forged steel pistons with stepped squish band, injectors with needle closing position sensor, liquid-cooled intercooler, electric compressor, 2 SCRs
	2020	Passenger vehicles	Jaguar Land Rover	D250 D300 D350	Inline 6	83.0 × 92.32	2,997	15.5	183/4,000 221/4,000 258/4,000	500/1,250-2,250 650/1,500-2,500 700/1,500-3,000	Mild hybrid, variable valves, cam needle bearings, sequential turbocharger, variable water/oil pumps
	2021	Commercial vehicles	Volvo	D13 TC	Inline 6	131.0 × 158.0	12,777	18.0	339/1,300-1,600 318/1,300-1,600 302/1,200-1,600	2,520/900-1,250 2,370/900-1,250 2,370/900-1,200	Ball bearing turbocharger, wave pistons, turbo-compound equipped as standard
	2021	Commercial vehicles	Detroit	DD15	Inline 6	139.0 × 163.0	14,840	21	339/1,500 377/1,550	2,373/1,000 2,508/1,100	Higher compression ratio, new swirl pistons, maximum peak firing pressure of 25 MPa, ball bearing/asymmetrical vortex turbocharger, high EGR ratio
	2021	Commercial vehicles	Detroit	DD13	Inline 6	132.0 × 156.0	12,809	20.3	336/1,500 392/1,620	2,373/900 2,508/1,000	New swirl pistons, maximum peak firing pressure of 25 MPa, ball bearing/asymmetrical vortex turbocharger, high EGR ratio
	2021	Commercial vehicles	Navistar	A26	Inline 6	126.0 × 166.0	12,419	20.5	384/1,800	2,500/900-1,400	Higher compression ratio, 250 MPa injection pressure, improved coolant passages, variable capacity water pump, lower engine speed

Fig. 1 Toyota F33A-FVT

Fig. 2 Audi V6 TDI

sensors to monitor closing of the needle valves, helping to realize stable and highly precise fuel injection. The maximum fuel injection pressure is set to 250 MPa, with eight injections per cycle. A liquid-cooled intercooler is provided that increases the boost pressure response by shortening the intake path. This also speeds up the increase in intake gas temperature after a cold start, which reduces engine emissions more quickly. The turbocharger uses a lightweight and compact compressor wheel to speed up response. An electric compressor driven by the 48 V system is used to supplement insufficient turbocharging performance in driving regions that generate low amounts of exhaust gases. The aftertreatment system consists of two selective catalytic reduction (SCR) systems, one directly below the engine and one on the vehicle side for compliance with the Euro 6d standards and to greatly lower NO_x emissions.

Fig. 3 JLR L6 Diesel

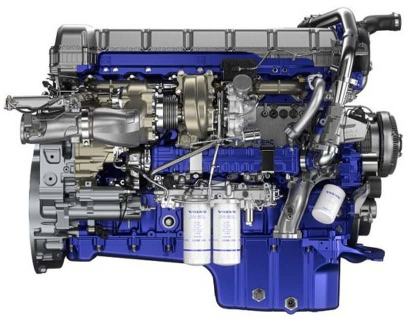

Fig. 4 Volvo D13TC

(2) JLR D250/D300/D350 (Fig. 3)

These aluminum inline 6-cylinder engines for SUVs were designed to comply with Euro 6d and are 80 kg lighter than the previous V8 diesel engine model (TDV8). The maximum fuel injection pressure reaches 250 MPa, with a possible maximum of five injections per cycle. The turbocharger system consists of two turbochargers arranged in series close to the engine. These turbochargers have two electrically variable nozzles and realize an impressive degree of control precision and flexibility, with the capability of generating up to 90% of maximum torque at 2,000 rpm in just over 1 second. In addition to the technologies for increasing engine efficiency that were already adopted on this engine series, such as needle roller rocker cam bearings as well as variable capacity oil and water pumps, the introduction of steel pistons and the latest exhaust gas recirculation (EGR) system helps these engines to reduce CO_2 emissions by 13% compared to vehicles installed with the TDV8 V8 diesel engine.

(3) Volvo D13TC (Fig. 4)

This engine is based on the conventional turbo-compound D13TC engine. Fuel economy was improved by at least 6% by changing the design of the piston geometry to improve combustion, adopting ball bearings in the turbocharger to lower friction, and switching to a low-viscosity engine oil. In addition, weight reduction measures such as decreasing the size and increasing the efficiency of the aftertreatment system lowers the TCO by improving the main engine unit and raising the fuel economy of the vehicle.

Fig. 5 Detroit DD15

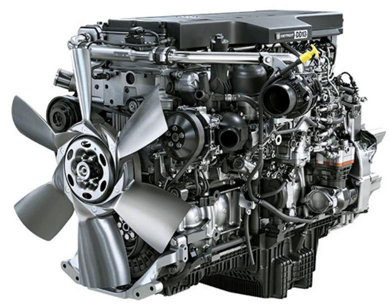

Fig. 6 Detroit DD13

(4) Detroit Diesel DD15 and DD13 (Figs. 5 and 6)

Based on the fifth-generation DD15 engine, the compression ratio was increased from 18.5 to 21, new swirl pistons adopted, and the peak firing pressure was raised from 23 to 25 MPa. The new DD15 engine also features an in-house manufactured turbocharger equipped with ball bearings. These measures help to raise the thermal efficiency of the engine in a wide range of operating regions to at least 48%. A 3% improvement in fuel economy was achieved in accordance with the reduction in engine speed, enabling compliance with Phase 2 of the U.S. GHG standards. The turbine housing generates two asymmetric vortices for adjusting the EGR flow rate and adjusting the air flow rate. This system realizes a maximum EGR ratio of 50%, substantially lowering NO_x emissions while also satisfying the GHG Phase 2 standards.

In the same way as the DD15 engine, the fifth-genera-

Fig. 7 Navistar A26

tion DD13 engine features improved combustion characteristics due to the adoption of new swirl pistons and lower friction due to a ball bearing turbocharger. These measures help to increase fuel economy by 4% and, similarly to the DD15 engine, satisfy Phase 2 of the U.S. GHG standards.

(5) Navistar A26 (Fig. 7)

More intense combustion was achieved by raising the compression ratio from 18.5 in the previous model to 20.5 and increasing the maximum fuel injection pressure to 250 MPa. The engine temperature was optimized by combining improvements to the coolant passages in the cylinder head with the adoption of a variable capacity water pump. Intake air volume control in a wide range of operating regions was optimized by adopting an EGR cooler, improved intake throttle valve, and enhanced variable geometry turbocharger (VGT). The engine speed was lowered throughout the normal operating region. The combination of these measures raised fuel economy by 4% and enabled the engine to comply with the 2021 GHG standards.

4 Research and Development Trends

As global initiatives for achieving carbon neutrality accelerate, it can be expected that automakers will further increase the pace of vehicle electrification projects. However, since vehicles are used under a wide range of market environments and usage scenarios depending on the use and the purpose of the vehicle, which ranges from passenger to commercial applications, automakers must also factor in user convenience and economic rationality. It is necessary to consider various technologies and means to help achieve carbon-neutral mobility, without narrowing down how this objective is realized. Diesel engines, including those for hybrid electric (HEVs) and plug-in hybrid electric (HEVs) vehicles, as well as the adoption of carbon-neutral fuels are also effective ways of realizing this objective in addition to battery electric vehicles (BEVs).

Presently, as a feasible method for achieving vehicle carbon neutrality, the introduction of carbon-neutral synthetic fuels refined using carbon recovered from the atmosphere and renewable hydrogen-sourced energy is being actively discussed. This is regarded as a net-zero approach for CO_2 emissions since it removes (re-uses) carbon from the air included in fuel and returns the CO_2 to the atmosphere via vehicle emissions when that fuel is used.

In April 2002, as one of the Green Innovation Fund Projects organized by the Japanese Ministry of Economy, Trade and Industry (METI), it was decided to develop efficient technologies for producing and using carbon-neutral synthetic fuels. Efforts are now under way to enable the social implementation of carbon-neutral synthetic fuels in Japan. In addition, as a means of reducing CO_2 emissions in the period before the social implementation of carbon-neutral synthetic fuels, the use of hydrogenated biofuels, which are more common in the European and U.S. markets, is likely to increase in recognition of their potential as carbon-neutral fuels through the utilization of renewable energy in the production process. However, issues include securing the biomass feedstock for hydrogenated biofuels and carbon-neutral synthetic fuels, as well as feedstock that can be refined using renewable energy. Competition with marine and aviation fuels is also likely to cause concerns over whether sufficient supply can be obtained for automotive fuels.

Although the social implementation of carbon-neutral fuels will take time, the reduction of CO_2 emissions is an urgent issue. Furthermore, achieving even slight reductions in engine fuel consumption is also likely to become a major topic. Improving fuel economy to reduce CO_2 emissions is already a well-established and constant development theme of automakers. Technologies to raise thermal efficiency, lower friction, and enhance thermal management are topics of continuous research and development even now. The further reduction of vehicle emissions and fuel consumption (i.e., the improvement of fuel economy) are likely to become even more important research and development trends in the future.