DIESEL ENGINES

1 Introduction

The application of the 2016 emissions regulations for diesel heavy-duty vehicles with a gross vehicle weight exceeding 3.5 t started in 2016 in Japan. Their application to diesel heavy-duty vehicles with a gross vehicle weight ranging from over 3.5 t to 7.5 t or less started in 2018. Automobile manufacturers took this opportunity to announce and launch new downsized engines or engines incorporating new technologies for the engines installed in that class of vehicles. These engines not only comply with the emissions regulations but also exceed the 2015 heavy-duty vehicle fuel economy standards.

Similarly, the emissions certification testing based on the WLTC mode started for passenger vehicles, and Mazda announced and launched a new engine that passes the test.

In Europe, various commercial vehicle engines compliant with Euro VI Step D were announced and launched, but little happened in the area of passenger vehicle engines.

There were also very few announcements and launches of new engines in North America, since engine manufacturers have completed their measures to comply with the 2017 greenhouse gas regulation (GHG17).

2 Trends in Japan

2. 1. Overview

2. 1. 1. Diesel Engines for Passenger Vehicles

Mazda announced and launched a new 1.8-liter engine for the CX-3 to replace the previous 1.5-liter engine.

2. 1. 2. Diesel Engines for Commercial Vehicles

With the 2016 emissions regulations for diesel heavy-duty vehicles with a gross vehicle weight ranging from over 3.5 t to 7.5 t or less coming into effect, Isuzu Motors launched the 4JZ1 3.0-liter engine for the Elf, and Mitsubishi Fuso Truck and Bus launched the 4V20 3.9-liter engine for the Fighter. Although it was launched in 2017, the Toyota 2GD-FTV 2.4-liter engine for the Hilux (mid-size vehicle) will be introduced in this article.

2. 2. New Engine Characteristics (Table 1)

2. 2. 1. Mazda S8-DPTS 1.8-Liter L4 (Fig. 1)

The displacement of the S8-DPTS engine for the CX-3 was changed from 1.5 to 1.8 liters to improve both actual fuel economy and environmental performance. Ultra-high response multi-hole piezo injectors and variable geometry single turbochargers are used to realize high torque in the high engine speed range(1).

2. 2. 2. Isuzu Motors 4JZ1 3.0-Liter L4 (Fig. 2)

The 4JZ1 for the Elf features revamped primary parts such as the cylinder block and cylinder heads, as well as precise control of the fuel injection amount based on variable exhaust valves and automatic injection accuracy compensation. It also uses a DPD and urea SCR after-treatment system. These enhancements, achieved not only increased fuel economy performance and compliance with the 2016 emissions regulations, but also exceeded the 2015 fuel efficiency standard by 10%(2).

2. 2. 3. Mitsubishi Fuso Truck and Bus 4V20 3.9-Liter L4 (Fig. 3)

The combustion efficiency of the 4V20 engine for the Fighter was improved with a common rail fuel injection system, and the NOx emissions were reduced using a high accuracy cooled exhaust recirculation (EGR) system. A waste gate turbocharger that finely controls the amount of exhaust gas and supercharging pressure was adopted to realize low fuel consumption at a level that exceeds the heavy-duty vehicle fuel economy standard by 5%(3).

2. 2. 4. Toyota 2GD-FTV 2.4-Liter L4 (Fig. 4)

The 2GD-FTV for the Hilux adopted a variable nozzle-type turbocharger, an air-cooled intercooler, and a common rail fuel injection system to realize powerful torque. Clean emissions were achieved by adopting exhaust gas purifier (DPR) and urea SCR systems. In addition, decreasing friction has increased fuel economy(4).

Table 1 Specifications of New Engines in 2018

Application	Manufacturer	Engine type	Cylinder arrangement	Bore diameter × stroke (mm)	Total displacement (cc)	Compression ratio	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Characteristics
Commercial vehicles	Isuzu	4JZ1	L4	95.4 × 104.9	2,999	17.3	110/2,800 129/2,860	375/1,280–2,800 430/1,450–2,860	Precise fuel injection control, variable exhaust valve, urea SCR, improvement of main engine structural parts
Passenger vehicles	Mazda	S8-DPTS	L4	79 × 89.6	1,756	14.8	85/4,000	270/1,600–2,800	Super high response multi-hole piezo injector, VGT
Commercial vehicles	Mitsubishi Fuso Truck and Bus	4V20	L4	104 × 115	3,907	16.5	125/2,500	520/1,500	Fuel injection pressure of 180 bar, cooled EGR, turbo with waste gate
Commercial vehicles	Toyota	2GD-FTV	L4	92 × 90	2,393	15.6	110/3,400	400/1,600–2,860	Variable nozzle-type turbo, common rail, friction reduction

Fig. 1 Mazda Skyactive-D 1.8 L

Fig. 2 Isuzu 4JZ1

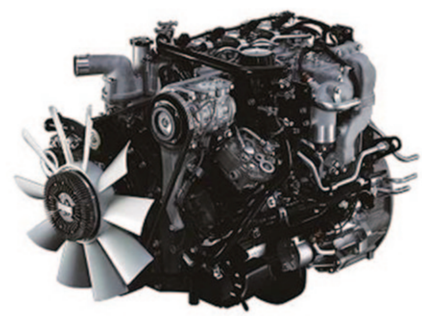

Fig. 3 FUSO 4V20

Fig. 4 Toyota 2GD-FTV

3 Trends outside Japan

3. 1. Overview

3. 1. 1. Diesel Engines for Passenger Vehicles

Jaguar launched the AJ200D 2.0-liter high power engine for passenger vehicles and SUVs.

3. 1. 2. Diesel Engines for Commercial Vehicles

Ford launched a 2.0-liter Bi-Turbo compliant with Euro 6 Step D, a high-power version of the EcoBlue engine, and MAN launched the D15 for use as a new engine for buses. Volvo unveiled the D11 and D13 improved engines compliant with Euro VI Step D. In North America, Cummins launched the high output (HO) ISB 6.7 for FCA full-size pickup trucks, while Ford launched the Power Stroke 3.0 L V6 for the same category of vehicles.

3. 2. New Engine Characteristics (Table 2)

3. 2. 1. Jaguar AJ200D 2.0-Liter L4 (Fig. 5)

The AJ200D, announced in 2016, shares about 30% of its parts with the AJ200P gasoline engine. The AJ200D is a highly efficient engine adopting a balancer shaft, roller bearing camshaft, electronically controlled oil pump, and electronically controlled coolant pump. This latest

Table 2 Specifications of New Engines Launched Outside Japan in 2018

Application	Manufacturer	Engine type	Cylinder arrangement	Bore diameter × stroke (mm)	Total displacement (cc)	Compression ratio	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Characteristics
Commercial vehicles	Cummins	ISB HO	L6	107 × 124	6,687	16.2	298/2,800	1,356/1,800	CGI cylinder block, forged con-rod, reduction of compression ratio, increase of head bolt diameter, injection pressure of 2,000 bar, improved VGT, improved cooling performance
Commercial vehicles	Ford	Bi-Turbo	L4	84 × 90	1,995	16.0	157/3,750	500/1,750–2,000	2 -stage turbocharger
Commercial vehicles	Ford	Power Stroke	V6	84 × 90	2,991	16.0	186/3,250	597/1,750	Aluminum head DOHC, CGI block, VGT with high efficiency, piezo injector of 2,000 bar
Passenger vehicles	Jaguar	D240	L4	83 × 92 .3	1,997	15.5	177/4,000	500/1,500	2 -stage turbocharger
Commercial vehicles	MAN	D15	L6	115 × 145	9,032	21.1	206/1,800 243/1,800 265/1,800	1,200/800–1,600 1,400/900–1,600 1,600/900–1,550	Leakless fuel injection system, coolant pump control, oil temperature control, refined EGR module
Commercial vehicles	Volvo	D11	L6	123 × 152	10,831	17.0	243/1,600–1,900 272/1,600–1,900 302/1,600–1,900 332/1,600–1,900	1,600/950–1,400 1,750/950–1,400 1,950/1,000–1,400 2,150/1,000–1,400	Refined engine control, refined aftertreatment coating
Commercial vehicles	Volvo	D13	L6	131 × 158	12,771	17.0	309/1,400–1,800 338/1,400–1,800 368/1,400–1,800 397/1,450–1,800	2,100/860–1,400 2,300/900–1,400 2,500/1,000–1,400 2,600/1,000–1,450	Refined engine control, refined aftertreatment coating, refined piston oil ring, low viscosity oil

Fig. 5 Jaguar AJ200D

Fig. 6 Cummins ISB HO

model for passenger vehicles and SUVs is further equipped with a 2-stage turbocharger to enable high output while lowering fuel consumption[5].

3. 2. 2. Cummins ISB HO 6.7-Liter L6 (Fig. 6)

The ISB HO was launched as a high-power engine for the Ram FCA full size pickup truck. The high output of this engine was enabled by enhancing and reinforcing the structural parts, improving cooling performance, and increasing the oil pump discharge amount. The improvements and reinforcements include the deep skirt compacted graphite iron (CGI) cylinder block, a revised piston design, the adoption of low friction piston rings and forged connecting rods, and a larger cylinder head bolt diameter. The fuel injection system was also revised, achieving a maximum injection pressure of 2,000 bar (1 bar = 100 kPa) by improving the high-pressure fuel injection pump and injector. Minor improvements were also made to the turbocharger[6].

3. 2. 3. Ford Power Stroke 3.0-Liter V6 (Fig. 7)

Greater quietness was achieved by adopting structural parts such as a CGI cylinder block, aluminum cylinder heads (4-valve DOHC), forged connecting rods, and a die cast oil pan. Highly efficient VGT, cooled EGR, and piezo injectors were adopted, and the maximum fuel injection pressure was set to 2,000 bar. This engine was mounted on the Ford F-150 full size pickup truck[7][8].

3. 2. 4. Ford Bi-Turbo 2.0-Liter L4 (Fig. 8)

A 2-stage turbocharger was installed on the EcoBlue 2.0-liter engine launched in 2017, greatly improving the engine output. This engine was mounted on the Ranger

Fig. 7 Ford Power Stroke 3.0 L

Fig. 8 Ford 2.0 L Bi-Turbo

Fig. 9 MAN D15

Raptor, a light-duty pickup truck[9].

3. 2. 5. MAN D15 9.0-Liter L6 (Fig. 9)

The D15 was announced as a new engine for buses. This engine was designed as a downsized version of the previous D20 model, and complies with the Euro VI Step D regulation. Downsizing the engine improved fuel efficiency and increased bus passenger capacity. In addition, thermal management such as coolant pump control and engine oil temperature control were introduced to improve fuel efficiency. In the fuel injection system, a leakless injector was installed in the common rail system, which has a maximum fuel injection pressure of 2,500 bar[10].

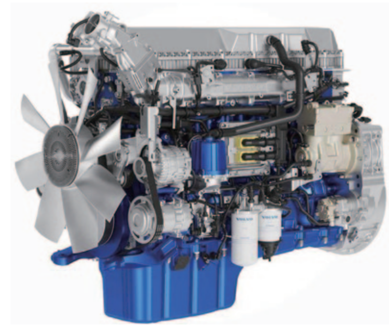

Fig. 10 Volvo D11

Fig. 11 Volvo D13

3. 2. 6. Volvo D11 10.8-Liter L6/D13 12.8-Liter L6 (Figs. 10 and 11)

In conjunction with Euro VI Step D compliance, Volvo improved the performance of its D11 and D13 engines for heavy-duty trucks. The main improvements were the update of engine control software and the coating of aftertreatment devices to comply with emissions regulations in the real world. The D13 engine achieved greater fuel efficiency by adopting a low viscosity engine oil with and refining the piston oil ring to reduce friction inside the engine[11].

4 Research and Development Trends

Social pressure not only to reduce the greenhouse gas (GHG), also to reduce emissions in the wake of the Dieselgate scandal, both passenger and commercial diesel vehicles in real world driving are growing stronger year by year. At the same time, the use of renewable fuels such as biofuels, led by Europe and the U.S. as part of GHG reduction policies, is also increasing in other markets outside Japan, making it essential to both support and accommodate diesel fuel diversity. In addition, implementing the CASE (Connected, Autonomous, Shared & Services, Electric) concepts in automobiles is necessary due to the rapidly growing demand for greater convenience and efficiency in everyday community life resulting from issues such as the aging of the population and labor shortages.

Responding to the various social expectations concerning diesel engines now, more than ever, requires making efforts to develop and refine engine and related basic technologies, and the scope of those efforts is predicted to expand. Further enhancements in engine combustion efficiency are necessary to reduce the GHG and emissions. The continuous development of technologies such as the optimization of engine hardware and fuel injection system, refinement of fuel injection control, strengthening of thermal management, and further elaboration of integrated control, including engine control, to improve the efficiency of aftertreatment devices are expected. Importance is also placed on the development of control technologies to respond flexibly to integrated technological development of control linked to CASE and to the diversification of diesel fuel.

Engine downsizing is an effective technology to reduce GHG, but also involves trade-offs such as increased engine loads. Technical development to secure durability and reliability that accounts for the effects of not only the structural system of engine itself, but also of the lubricant and cooling systems used for thermal management, is required. Securing the durability and reliability of aftertreatment devices is an important issue in terms of maintaining a sustainable reduction of emissions in the real world. Developing technologies to ensure the durability and reliability on aftertreatment devices considering characteristics of exhaust emissions from engine is crucial.

For commercial vehicles, in particular, reducing the (initial and running) user cost burden represents one of the social expectations placed diesel engines, and in conjunction with the above mentioned technical development, is expected to accelerate the integration and simplification of functions.

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