DIESEL ENGINES

1 Introduction

The deadline for applying “the Japan 2016 emissions regulations” or “the 2016 emission regurations in Japan” for diesel heavy-duty vehicles (with a gross vehicle weight exceeding 3.5 t) to medium- and heavy-duty trucks was autumn 2017. Commercial vehicle manufacturers in Japan developed a succession of new engines that conform with these regulations. The deadline for applying the regulations to heavy-duty tractors is autumn 2018, and autumn 2019 for light-duty trucks with a gross vehicle weight of 7.5 t or less. Therefore, the release of the entire spectrum of engines will have to wait until 2019.

No new remakable technical … advances designed to conform to the emissions regulations for new Japanese commercial vehicle engines were observed, and the technologies adopted in the engines are basically the same as those developed for previous regulations. However, ambitious technologies that exceed the 2015 fuel efficiency standard to achieve further improvements in fuel efficiency while downsizing the engine are being announced.

New commercial vehicle engines for countries other than Japan were announced and launched in 2016 to conform to the 2017 Greenhouse Gas (GHG17) regulations in North America. Consequently, no remarkable new engine for trucks and buses appeared in either North America or Europe.

In contrast to new commercial vehicle engines in Japan, announcements and launches of new passenger vehicle engines were very few both in Japan and other countries due to the influence of Dieselgate and other factors.

2 Trends in Japan

2. 1. Overview

2. 1. 1. Diesel Engines for Passenger Vehicles

As stated above, not many passenger vehicle engines were developed in 2017, with the only launch being the 2.2 L SH-VPTS engine from Mazda Motor Corporation, which improved output power (140 W) for the new CX-8.

2. 1. 2. Diesel Engines for Commercial Vehicles

New engines for heavy- and medium-duty trucks complying with the new emissions regulations were announced and launched in succession by automakers in Japan. As in past regulation compliance technology to reduce emissions, the engine uses a combination of high pressure fuel injection and cooled EGR while the after treatment system combines DPF and SCR. Compliance with the current regulation was achieved through the refinement of elemental technologies such as the improved catalytic performance and adaptive control of the whole system typified by model base control.

Another trend is to reduce size and weight by changing of the structure of the engine series of the vehicle to have a smaller displacement. Engine structure, main components and turbocharging system of the new engines have been improved to give engines with smaller displacements the same level of output power and torque as previous engines. In particular, the use of 2-stage turbochargers, which have a high and a low pressure turbocharging stage, is increasing. In general, increasing the brake mean effective pressure in accordance with the reduction in size is one of the measures used to improve fuel efficiency. It also addresses the requirement to improve truck load capacity through weight reduction, making its continued use in commercial vehicle engines likely.

Since fuel efficiency has a trade-off relationship with NOx reduction, the influence of measures to adapt the engine to the new emissions regulations was a concern. However, with the adoption of technologies to improve fuel efficiency, such as the reduction in size and engine friction mentioned above, a growing number of models not only satisfy the heavy-duty vehicle fuel economy standards, but even exceed them by 5 to 10%.

Table 1 Specifications of diesel engines announced and launched in 2017

	Application	Manufacturers	Engine type	Cylinder arrangement	Bore diameter × stroke (mm)	Total displacement (L)	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)
Japan	Passenger vehicles	Mazda	SH-VPTS	L4	86 × 94.2	2.188	140/4,500	450/2,000
Outside Japan	Passenger vehicles	Ford	EcoBlue 2.0	L4	84 × 90	1.995	125/3,500	405/1,500–2,000
Japan	Commercial vehicles	Hino	E13 C	L6	137 × 146	12.913	302/1,700	2,157/900–1,300
Japan	Commercial vehicles	Hino	A09 C	L6	112 × 150	8.866	279/1,700	1,765/1,100–1,400
Japan	Commercial vehicles	Hino	A05 C	L4	112 × 130	5.123	191/2,300	882/1,400
Japan	Commercial vehicles	Hino	N04 C	L4	104 × 118	4.009	132/2,800	480/1,400
Japan	Commercial vehicles	Isuzu	6 UZ1	L6	120 × 145	9.839	279/1,800	1,814/1,000–1,200
Japan	Commercial vehicles	Isuzu	6 NX1	L6	115 × 125	7.790	250/1,800	1,422/1,300
Japan	Commercial vehicles	Isuzu	4 HK1	L4	115 × 125	5.193	177/2,400	765/1,600
Japan	Commercial vehicles	Mitsubishi Fuso	6 R20	L6	125 × 145	10.676	338/1,600	2,200/1,100
Japan	Commercial vehicles	Mitsubishi Fuso	6 S10	L6	110 × 135	7.697	280/2,200	1,400/1,200–1,600
Japan	Commercial vehicles	Mitsubishi Fuso	6 M60	L6	118 × 115	7.545	199/2,500	785/1,100–2,400
Japan	Commercial vehicles	Mitsubishi Fuso	4 P10	L4	95.8 × 104	2.998	129/2,860–3,500	430/1,600–2,860
Japan	Commercial vehicles	UD Truck	GH11	L6	123 × 152	10.836	339/1,800	2,200/1,200

Fig. 1 Mazda SH-VPTS

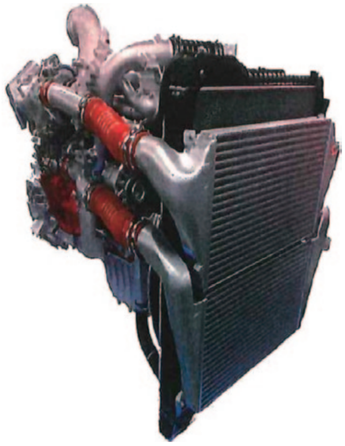

Fig. 2 Hino A09C

2.2. New Engine Characteristics (Table 1)

2.2.1. Mazda SH-VPTS (Fig. 1)

To improve the output power for the CX-8 (SUV) compared with the existing 129 kW specification, combustion performance was improved with the use of stepped egg-shaped pistons and multi-hole piezoelectric injectors, and the low pressure stage of the 2-stage turbocharger was replaced with a variable geometry turbocharger. Such improvements result in an output power of 140 kW(1).

2.2.2. Hino A09C (Fig. 2)

This engine, which has already been mounted on the Profia heavy-duty truck, covered the low power range, and the high power 279 kW specification was added in the process of complying with the new emissions regulations. This new specification includes a 2-stage turbocharger and, a first for trucks, also features two air-cooling type intercoolers. Both the high- and low pressure stages use a conventional turbocharger, with high pressure stage bypass only provided on the turbine side. The intercoolers are set not only at downstream of the high pressure stage but also at between two turbochargers, improving total turbocharging efficiency.

This achieves an output power range of 279 kW, the main output power range for heavy-duty trucks, with an engine displacement of 8.9 L, a successful size reduction compared to the previous 12.9 L engine. Emissions regulation were addressed by improving the SCR capacity and catalyst quality to reduce NOx while retaining the conventional DPF and urea SCR configuration as is. In addition, friction loss was reduced by adopting the cylinder liners with dimple texture used in the A05C engine for medium-duty trucks, allowing some models to exceed

Fig. 3 Isuzu 4HK1

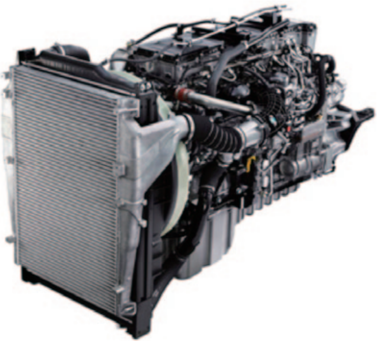

Fig. 4 Mitsubishi Fuso Truck and Bus 6R20

the heavy-duty vehicle fuel economy standards by 10%.

2. 2. 3. Hino A05C

The output power of the A05C 4-cylinder 5.1 L engine launched in 2015 was improved and variations were expanded for use in the Ranger medium- and medium-heavy-duty truck. All the previous J-series 4, 5, and 6-cylinder engines were replaced by this new engine. A detailed and precise configuration adapted to the model is used. Specifically, the engine uses a 2-stage turbocharger for engines with the maximum power of 191 kW and a single stage turbocharger for other models, and the choice of HC-SCR or urea SCR for the after treatment system is also based on power(2).

2. 2. 4. Isuzu 6UZ1

This is the main engine used in the Giga heavy-duty truck. Compliance with the regulations was achieved without sacrificing output power or fuel economy by optimizing the fuel injector injection specifications and turbo specifications to improve the combustion performance of the engine. The performance of the after treatment system was enhanced by increasing the catalyst capacity and changing those specifications, and mechanical loss was reduced through the adoption of items such as oil pumps with electronically controlled release valves. In addition, changes to further improve durability and reliability have been incorporated. Measures such as switching to a butterfly EGR valve moved upstream of the EGR cooler and to steel pistons were incorporated to cope with the rise in cylinder pressure and increased load on parts, as well as to calibrate the EGR flow rate(4)(5).

2. 2. 5. Isuzu 6NX1

This 7.8 L engine, also launched in 2016 for heavy-duty trucks, relies on a 2-stage turbocharger to achieve an output of 250 kW despite a small displacement. Refinements to the after treatment system allow the latest version to comply with the new emissions regulations while maintaining the same levels of output and fuel economy. The 228 kW specification version of this engine is mounted on the Forward medium-heavy-duty 6x4 truck(4).

2. 2. 6. Isuzu 4HK1 (Fig. 3)

The 5.2 L diesel engine for the Forward medium-duty truck also complies with the new emissions regulations while keeping the same levels of output and fuel economy. This engine covers the power range of current 6-cylinder engines, thus replacing them, while also adopting a 2-stage turbocharger for the high power 177 kW specification(4).

2. 2. 7. Mitsubishi Fuso Truck and Bus 6R20 (Fig. 4)

This engine is a new 10.7 L, 6-cylinder engine developed for the Super Great heavy-duty truck to replace the previous 12.8 L engine. The basic structure of the engine is commonized within the Daimler Group, and achieves both size and weight reductions while offering variations built to cover the 265 to 338 kW power range of heavy-duty trucks and tractors.

This engine has a distinct EGR system which uses a new EGR valve and adopts an asymmetric turbocharger with different turbine gas inlet shapes for the three front cylinders and the three rear cylinders. This design allows the recirculation of all exhaust gas flow from the three front cylinders to the intake side. The second-generation X-Pulse system that enables a maximum injection pressure of 2,700 bars is used for the injection system. In addition, the injection volume of the three front cylinders and the three rear cylinders are controlled separately, and a function to maintain the emission temperature is adopted to capitalize on the characteristics of the EGR mentioned above, securing the catalytic performance of the after treatment system. The engine complies with the new emissions regulations thanks to the

Fig. 5 UD Truck GH11

adoption of the above systems and the DPF and SCR combination featuring a refined catalyst.

Some heavy-duty tractor models have exceeded the heavy-duty vehicle fuel economy standards by as much as 10% with the above new technologies(3)(6).

2. 2. 8. Mitsubishi Fuso Truck and Bus 6S10

This heavy-duty truck engine reduces size and displacement even further. While this 7.7 L 6-cylinder engine also uses the basic structure common to the group, the use of 2-stage turbochargers enables the engine to reach a maximum power of 280 kW. The variable valve timing system employing a DOHC layout to change the phase of the exhaust camshafts, a first for commercial vehicles in Japan, is used to control the exhaust temperature management to ensure after treatment performance. A compression release auxiliary engine braking system is installed to address braking performance concerns due to the small displacement(3)(6).

2. 2. 9. UD Trucks GH11 (Fig. 5)

This 10.8 L-engine is mounted on the Quon heavy-duty truck, with a high power 339 kW specification added in the process of complying with the new emissions regulations. It replaces the current 12.8 L engines in heavy-duty tractors, leading to a reduction in size. The improved performance exceeds the heavy-duty vehicle fuel economy standards by 5% in all models, while retaining the common engine structure with other Volvo group engines for the European and North American markets.

The fuel injection system uses a common rail system with a current unit injector layout, which combines with the change in the combustion chamber shape to improve combustion performance. In addition, the catalyst specification was changed and the capacity for the after treatment system was reviewed. Items that reduce mechanical loss due to the variable coolant pump have also been adopted(3)(7).

Fig. 6 Ford EcoBlue 2.0

3 Trends outside Japan

3. 1. Overview

3. 1. 1. Diesel Engines for Passenger Vehicles

In Europe, barely any new engines were launched due to the strong backlash against diesel engines for passenger vehicles, and the introduction of new products is unlikely in the foreseeable future. Although it was actually unveiled in 2016, the Ford EcoBlue 2.0 engine will be featured here due to its intriguing structure.

3. 1. 2. Diesel Engines for Commercial Vehicles

As described earlier, 2016 saw the launch of many new engines to complying with the GHG17 regulations in North America, and the announcement of refinements to many engines to comply with the Euro IV Step C regulations in Europe. Thus, no new engines for this article to showcase were launched in 2017.

3. 2. New Engine Characteristics

3. 2. 1. Ford EcoBlue 2.0 (Fig. 6)

This is a 2.0 L 4-cylinder engine newly developed mainly for SUVs and one-box vans. It has 125 kW of power and uses the mainstream combination of a common rail system with multi-injection hole piezo injectors, a variable geometry turbocharger, and a DPF and urea SCR after treatment system. Its distinctiveness lies in the engine structure itself. The crankshaft is offset from the cylinder shaft by 10 mm to reduce friction, and rigidity is secured through a ladder frame structure that reduces noise. The intake manifold is integrated with the cylinder head, with the EGR passage also set within the cylinder head. The innovative structure of this new engine incorporates approaches such as giving the intake ports of the first and second cylinders, and of the third and fourth cylinders, a symmetric (mirrored) shape, which reverses the direction of the swirl at the front and rear of the engine while reducing cylinder EGR and other variation(8).

4 Research and Development Trends

Growing concerns about environmental and energy issues have led to the strengthening of emissions- and fuel-efficiency-related regulations around the world. In that context, achievements from research and development on low emission and even more fuel efficient diesel engines are being adopted in new engines. As explained in the previous sections, new engines achieve performance that satisfies stringent demands through downsizing, model base control, and higher-performance after treatment catalysts, which represent the trends in recent diesel engine development.

The basic technology that supports such development, systems that connect the technologies, and development that aim for the optimization between systems will remain critical issues in the research and development of engines. Research and development will undoubtedly continue to be pursued actively in areas such as the optimization of injection and in-cylinder flow to enhance mixture formation, combustion systems that reduce cooling loss, air management system to achieve highly efficient supercharging and EGR, piston and cylinder system / valve system including the adoption of low friction materials / surface treatments as well as of low viscosity lubricants, and exhaust gas aftertreatment systems to reduce emissions efficiently(9). The notable advances in downsizing in diesel engines for commercial vehicles is expected to make research and development in the fields of engine structural design and tribology even more important in the years to come.

Future regulation requirements and market demands will not be limited to stipulated test conditions, but will emphasize fully achieving low emissions and low fuel consumption under any and all conceivable driving conditions on typical real-world roads. Thus, engine systems with greater robustness than ever will be required. For example, there are calls for temporal and spatial control of the mixture formation in the combustion, and for the development of control systems that achieve these results on-board, and their concrete realization is awaited.

Finally, for both passenger and commercial vehicles, development processes that integrate the above advanced technologies while addressing global market needs and satisfying design requirements such as packaging, parts commonization, weight, and cost are becoming increasingly extensive and complex. Efforts to develop simulation models to support these development processes are predicted to intensify(10)(11).

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