DIESEL ENGINES

1 Introduction

The 2016 emissions regulations for diesel heavy-duty vehicles (with a gross vehicle weight exceeding 3.5 t) entered into force in Japan in October 2016. Automobile manufacturers are expected to gradually introduce new engines compliant with these latest regulations into the market, but no such engines were announced or launched in 2016.

In this context, only Isuzu Motors announced and launched a new 7.8-liter engine for heavy-duty trucks. This downsized engine complies with the previous post-new long-term emissions regulations and achieves the 2015 fuel efficiency standard in anticipation of an adaptation to the latest emission regulations and fuel efficiency standards.

Meanwhile, a number of engines were announced and launched outside Japan, including in the North American market. They include new engines with higher power output for pickup trucks, as well as, in the medium- and heavy-duty trucks and buses category, new and upgraded engines that suppress CO_2 emissions and enhance fuel efficiency to comply with 2017 greenhouse gas regulations (GHG17).

2 Trends in Japan

2. 1. Overview

2. 1. 1. Diesel Engines for Passenger Vehicles

European passenger vehicle manufacturers have been extensively expanding the introduction of diesel engines in Japan. In contrast, Japanese manufacturers did not announce or launch new diesel engines in 2016.

2. 1. 2. Diesel Engines for Commercial Vehicles

Isuzu Motors announced and launched the 6NX1-TCS 7.8-liter engine presented as a reference exhibit at the 2015 Tokyo Motor Show, which boasts the smallest size in the class of engines for full-scale heavy-duty trucks.

2. 2. New Engine Characteristics (Table 1)

Isuzu 6NX1-TCS (Fig. 1)

This lightweight and compact engine based on the current 6HK1 was newly developed for the Giga heavy-duty truck to comply with the post-new long-term emission regulations and to achieve the 2015 fuel efficiency standard. In spite of a smaller displacement than conventional engines for heavy-duty trucks, the use of a 2-stage turbocharger provides a maximum output of 250 kW/2000 rpm and a maximum torque of 1422 Nm/1300 rpm, achieving stable torque characteristics through a broad range of low to high engine speeds. To ensure engine braking performance, an area of concern due to the smaller displacement, the 6NX1-TCS employs an engine retarder (compression release engine brake) with dedicated cam profiles. The 6NX1-TCS has the same features as the 9.8-liter 6UZ1 engine, already available in the new GIGA. This includes offering the ecostop system, which automatically stops and restarts the engine to minimize unnecessary fuel consumption during idling, as standard equipment, as well as the adoption of an HC doser with an exhaust pipe injection system to add hydrocarbons during DPF regeneration.

3 Trends outside Japan

3. 1. Overview

3. 1. 1. Diesel Engines for Passenger Vehicles

Since the main European passenger vehicle manufacturers have completed the first stage of the introduction of Euro 6 compliant engines into the market, few new models were announced and launched in 2016. Several new engine models with improved fuel efficiency and output power for pickup trucks in Southeast Asia and North America were announced and launched to meet market needs.

3. 1. 2. Diesel Engines for Commercial Vehicles

Manufacturers outside Japan announced and launched a number of upgraded engines for medium- and heavy-

Table 1 Specifications of engines announced and launched in Japan in 2016

Application	Manufacturer	Engine model	Cylinder arrangement	Bore diameter × stroke (mm)	Total displacement (L)	Compression ratio	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)
Commercial vehicles	Isuzu	6NX1-TCS	L6	115 × 125	7.790	16.5	250 /2 000	1 422 /1 300

Table 2 Specifications of engines announced and launched outside Japan in 2016

Application	Manufacturer	Engine model	Cylinder arrangement	Bore diameter × stroke (mm)	Total displacement (L)	Compression ratio	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)
Passenger vehicles	Isuzu	RZ4E-TC	L4	80 × 94.4	1.898	16.5	112 /3 600	350 /1 800−2 600
	GM	Duramax L5P	V8	103 × 99	6.604	16.0	332 /2 800	1 234 /1 600
	Cummins	5.0 L V8 Turbo Diese1	V8	94 × 90	4.997	16.3	231 /3 200	752 /1 600
Commercial vehicles	Cummins	L9	L6	114 × 144.5	8.849		283 /	1 695 /1 400
		X15	L6	137 × 169	14.948	18.9	372 /1 500−1 700	2 508 /1 000
	Detroit diesel	DD5	L4	110 × 135	5.132	17.6	172 /2 200	895 /14 000
	Mercedes-Benz	OM470	L6	125 × 145	10.677	18.5	335 /1 600	2 200 /1 100
	Volvo (Mack)	D11 (MP7)	L6	123 × 152	10.837	17.0	317 /1 500−1 800 (317 /1 500−1 800)	2 102 /1 000 (2 115/1 050−1 200)
		D13 (MP8)	L6	131 × 158	12.777	17.0	372 /1 500−1 700 (377 /1 500−1 700)	2 508 /1 000 (2 522/1 150−1 400)
	Paccar	MX-11	L6	123 × 152	10.837	17.5	321 /1 600	2 237 /900
		MX-13	L6	130 × 162	12.902	16.5	380 /1 600	2 508 /1 000

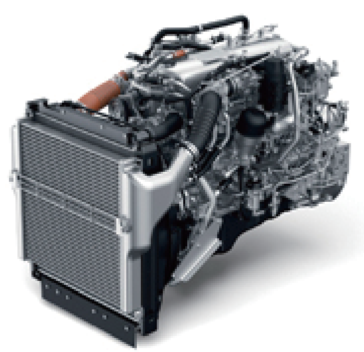

Fig. 1 Isuzu 6NX1-TCS

duty trucks. To comply with GHG17 in the North American market, the fuel efficiency of these engines was improved by revising the turbochargers based on current engines, using ultra-high pressure fuel injection, and reducing friction through approaches such as adopting oil and water pumps equipped with electronically controlled variable mechanisms.

3. 2. New Engine Characteristics (Table 2)

3. 2. 1. Isuzu RZ4E-TC (Fig. 2)

This 1.9-liter DOHC 4-cylinder engine newly developed for the D-Max pickup truck intended for markets outside Japan provides a maximum output of 112 kW/3600 rpm and a maximum torque of 350 Nm/1800-2600 rpm. This successor to the 2.5-liter 4JK1 engine was downsized to reduce its weight, and the torque per displacement (mean effective pressure) was increased to improve fuel efficiency.

Fig. 2 Isuzu RZ4E-TC

3. 2. 2. GM Duramax L5P (Fig. 3)

This is a 6.6-liter V configuration 8-cylinder 32-valve (OHV) engine newly designed based on the current LML engine for GMC and Chevrolet pickup trucks destined for North America. The journal diameter and pin diameter of the crankshaft were changed, and four bolts were used for the main bearing cap. With this reinforced body

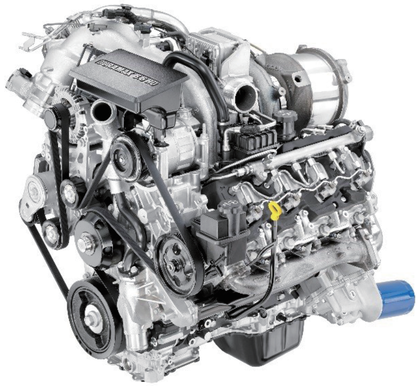

Fig. 3 GM Duramax L5P

Fig. 4 Cummins 5.0 L V8 Turbo Diesel

Fig. 5 Cummins X15

Fig. 6 Detroit Diesel DD5

structure and improved boost pressure due to optimized VG turbocharger specifications, the Duramax L5P achieves a maximum torque of 1234 Nm/1600 rpm (an increase of 19% over the LML engine). Noise reduction measures, such as applying sound insulating foam rubber on the upper rocker cover, were also carried out, reducing noise at idle by 38% compared to the previous model.

3. 2. 3. Cummins 5.0 L V8 Turbo Diesel (Fig. 4)

This DOHC V configuration 8-cylinder 32-valve engine was newly developed for Nissan the Titan XD pickup truck destined for North America based on the current ISV5.0 engine. It achieves a maximum output of 231 kW/3200 rpm through a high pressure common rail (HPCR) system using piezo injectors and the adoption of a new Cummins 2-stage turbocharger. In addition, the 2-stage fuel filter system improves the robustness of the common rail system against fuel contamination.

3. 2. 4. Cummins L9

This engine for North American medium-duty trucks uses the same Cummins VG turbocharger and the XPI Fuel System (high pressure common rail system) as the current ISL9 engine, and complies with GHG17 standards. The adoption of the Connected Diagnostics™, remote diagnostic system using telematics has improved operation management and serviceability.

3. 2. 5. Cummins X15 (Fig. 5)

This engine developed for heavy-duty trucks in North America is available in two variants, the Performance Series and Efficiency Series, which have different output and torque characteristics. Compared to the current ISX15, it brings improvements such as the optimization of the compression ratio, cam profile, VG turbocharging and fuel injection pressure to comply with the GHG17 standards. Like the L9, the X15 also features the Connected Diagnostics system.

3. 2. 6. Detroit Diesel DD5 (Fig. 6)

Based on the Mercedes-Benz OM934 engine, this 5.1-liter DOHC 4-cylinder 16 V engine for the Freightliner M2 medium-duty truck destined for North America was designed to comply with the GHG17 standards. In spite of its small displacement, the 2-stage turbocharger provides a maximum output of 172 kW/2200 rpm and a maximum

Fig. 7 Mercedes-Benz OM470

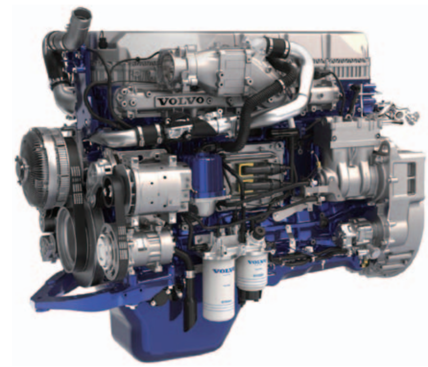

Fig. 8 Volvo Trucks D11

Fig. 9 Wave combustion chamber design

Fig. 10 Paccar MX-11

torque of 895 Nm/1400 rpm. As with the OM934 engine, the Detroit Diesel DD5 adopts a compression release engine brake as well as a variable exhaust valve timing mechanism that uses camshaft phasing to raise the exhaust temperature during DPF regeneration. In addition, the use of the Detroit™ Connect Virtual Technician℠ remote diagnostic system, has improved operation management and serviceability.

3. 2. 7. Mercedes-Benz OM470 (Fig. 7)

Like the 12.8-liter OM471 Euro VI compliant engine introduced as an early second generation engine in 2015, this engine further lowers fuel consumption by complementing the increased maximum injection pressure (up to 2700 bar) of the X-Pulse common rail system with pressure booster, the in-house asymmetric turbocharger, and the revision of the EGR flap valve position with other features such as a higher compression ratio, and an optimized combustion chamber shape. At the same time, emissions control devices were simplified by eliminating the EGR differential pressure sensor and relying on asymmetric injection to raise exhaust temperature during DPF regeneration, and the body of the engine was made more robust.

3. 2. 8. Volvo Trucks D11 (Fig. 8), D13, and Mack MP7 and MP8

These engines were developed for heavy-duty trucks in North America and adopt a hybrid common rail system with a maximum injection pressure of 2400 bar that utilizes the same jerk type unit injector pressure boosting mechanism that was used as a fuel supply pump in previous engines. Fuel efficiency was improved through the use of a wave combustion chamber design (Figure 9) and a combination of innovations including a two-speed water pump and variable speed fans. Turbo compounding, available as an option for D13 engines, improves output by 37 kW and fuel efficiency by 6.5%.

3. 2. 9. Paccar MX-11, MX-13 (Fig. 10)

Fuel efficiency was improved by innovations that include the adoption of a variable capacity oil pump, variable-speed water pump, and new single cylinder air compressor, as well as the reduction of the engine speed at which maximum torque is generated. Furthermore, the maximum output of the MX-13 was increased to 380 kW, while the maximum torque of the MX-11 was increased to 2237 Nm. A remote diagnostic function was also used to improve operation management and serviceability.

4 Research and Development Trends

In an effort to further reduce air pollution, the 2016 emission regulations, which call for Japanese diesel heavy-duty vehicles to satisfy requirements as strict as those for European diesel vehicles, came into force. This has also made it necessary to strengthen regulations on nitrogen oxides (NO_x), comply with the global technical regulations covering test modes and off-cycle emission in the WHDC procedure.

At the same time, the demands imposed on diesel engine vehicles are becoming even more stringent as compliance with existing fuel efficiency standards have become a matter of course and even further fuel economy improvements are called for to prevent global warming and meet market needs.

To address these demands, existing technologies, including fuel injection pressure boosting, enhanced turbocharging through improved turbocharger performance and 2-stage turbochargers, revisions to the shape of the combustion chamber and EGR optimization, better NO_x conversion efficiency using Cu-SCR, and reduced friction based on auxiliary devices with electronically controlled variable mechanisms, will continue to be refined. At the same time, further progress is expected in the development of technologies that increase fuel efficiency at the level of the vehicle as a whole, such as combining multi-stage transmission with the downsizing and a reduction of the speed of the engine.

The harmonizing regulations on emissions and OBD, and the need to reduce the development costs imposed by coping with tighter fuel efficiency standards and setting up remote diagnostic systems is expected to further spur the advance of globalization in the years ahead via the joint development of engines, including the control technologies in Japan, the US, and Europe, and the commonization of the engine body, for both passenger vehicles and commercial vehicles.

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