Diesel Engines

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1 Introduction

In 2012, 1.032 million automotive diesel engines were produced in Japan, 8.0% more than the previous year. In terms of engine types, 328,000 diesel engines were produced for passenger vehicles (2.0% less than the previous year), 624,000 diesel engines were produced for trucks (12.9% more than the previous year), and 79,000 diesel engines were produced for buses (17.9% more than the previous year).

Although the production of passenger vehicle diesel engines was roughly unchanged from 2011, production of diesel engines for trucks and buses increased due to recovering demand after the Great East Japan Earthquake and other reasons. However, production has yet to recover to the pre-earthquake level of 1.2 million units, partly due to the effects of the chronic appreciation in the yen.

On a month-by-month basis, the production of truck diesel engines gradually declined over the course of the year, while the production of diesel engines for passenger vehicles and buses remained steady (Fig. 1).

Automakers in Japan completed measures for compliance with the 2009 and 2010 emissions regulations (the post new long-term regulations). Consequently, there were few new engine announcements and launches, except for modifications to existing engines to enable compliance with the 2015 heavy-duty vehicle fuel economy standards.

Outside Japan, Europe will introduce more stringent emissions regulations in 2013 (Euro VI). As a result, automakers have been announcing and launching a series of new vehicles and engines. In contrast there were few announcements of new engines in the U.S., since emissions regulations remained unchanged.

As customers around the world become more concerned about fuel efficiency and the environment, competition is growing more intense to develop engines and after-treatment systems that achieve clean emissions as well as low fuel consumption and CO_2 emissions.

2 Engine Trends in Japan

2. 1. Overview

2. 1. 1. Diesel engines for passenger vehicles

The development of diesel engines for passenger vehicles in Japan has been held back by strict emissions regulations and low customer demand. Therefore, the launch of the new SH-VPTS engine from Mazda attracted a great deal of attention. This engine is installed in the CX-5 and achieves both excellent environmental and dynamic performance. Mazda successfully developed the SH-VPTS with a low compression ratio and a simplified after-treatment system, complying with Japanese emissions regulations without the use of a high-cost after-treatment system, such as urea selective catalyst reduction (SCR) or the like.

2. 1. 2. Diesel engines for commercial vehicles

2012 saw the launch of vehicles with enhanced safety performance to comply with new safety standards. However, automakers launched virtually no new commercial vehicle engines since measures to comply with Japan's post new long-term regulations have almost been com-

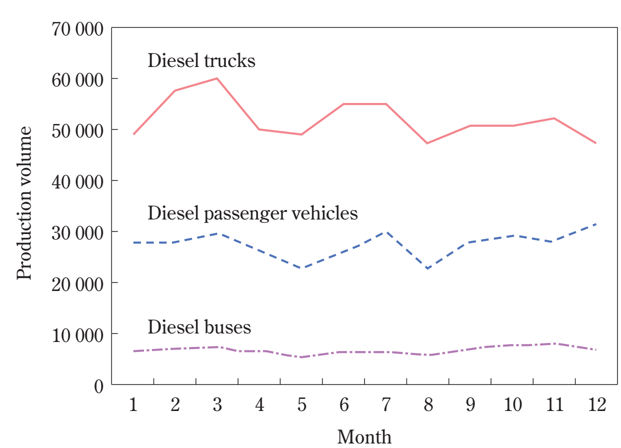

Fig. 1 Monthly diesel engine vehicle production in 2012[(1)].

Table 1 Specifications of new engines announced and launched in Japan in 2012.

Application	Manufacturer	Model	Combustion	Intake	Cylinders	Bore × stroke (mm)	Displacement (cc)	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)
Passenger vehicles	Mazda	SH-VPTS	DI	TCI	L4	86 × 94.2	2 189	129/4 500	420/2 000
	Mitsubishi	4N14	DI	TCI	L4	89 × 97.6	2 268	109/3 500	360/1 500–2 750
Commercial vehicles	Nissan	YD25DDTi	DI	TCI	L4	89 × 100	2 488	95/3 200	356/1 400–2 000
		ZD30DDTi	DI	TCI	L4	96 × 102	2 953	88/2 400	350/1 200–2 400
	Hino	N04C	DI	TCI	L4	104 × 118	4 010	132/2 800	480/1 400
	Isuzu	4HK1	DI	TCI	L4	115 × 125	5 193	177/2 400	756/1 600
		6HK1	DI	TCI	L6	115 × 125	7 790	221/2 400	960/1 450

DI: direct injection, TCI: turbocharger intercooler, L4: inline 4-cylinder

Fig. 2 Mazda SH-VPTS.

pleted. Instead of new engines, automakers announced measures to comply with the 2015 heavy-duty vehicle fuel economy standards through the addition of fuel injection systems, exhaust gas recirculation (EGR), and after-treatment systems to existing engines. Other trends included the adoption of truck engines on buses and the application of diesel engines to hybrid vehicles.

2. 2. New engine characteristics (Table 1)

2. 2. 1. Mazda SH-VPTS (Fig. 2)

The SH-VPTS engine is installed on the CX-5 and Atenza. It features a 2-stage turbocharger, common rail multi-hole piezo injectors, a low compression ratio, and a variable valve lift mechanism. Due to these innovations, the engine complies with the post new long-term regulations and achieves emissions 20% below the 2015 fuel economy standards on certain models, without the use of a high-cost NOx after-treatment system [2].

2. 2. 2. Mitsubishi 4N14

Installed on the Delica D:5, this engine features a variable geometry (VG) turbocharger, common rail, and a low compression ratio. It complies with the post new long-term regulations and achieves emissions 20% below the 2015 fuel economy standards [3].

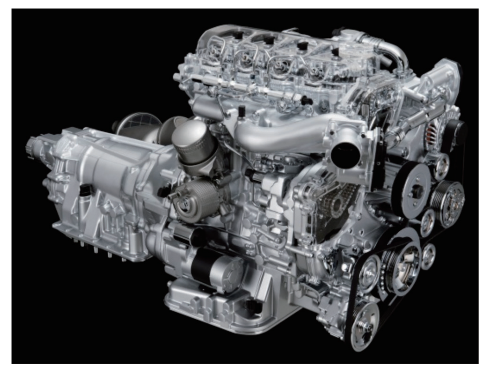

Fig. 3 Nissan YD25DDTi.

2. 2. 3. Nissan YD25DDTi (Fig. 3)

This engine is installed on the Nissan NV350 Caravan and the Isuzu Como. It features electronically controlled EGR valves, an electronically controlled VG turbocharger, a 2,000 bar common rail system, parallel port cylinder heads, and small-diameter nozzle hole injectors. In combination with a high-capacity and high-efficiency diesel particulate filter (DPF) and lean NOx trap catalyst, the engine complies with the post new long-term regulations and some models achieve emissions 10% below the 2015 fuel economy standards [4].

2. 2. 4. Nissan ZD30DDTi

Installed on the Nissan Atlas, and Mitsubishi Fuso Canter Guts, this engine features cooled EGR, a VG turbocharger, and common rail system. In combination with a DPF, it complies with the post new long-term regulations and achieves the 2015 fuel economy standards [5].

2. 2. 5. Hino N04C

Installed on the Dutro, this engine uses a new ureafree DPR system. It complies with the post new long-term regulations and, except for certain models, achieves the 2015 fuel economy standards [6].

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

This engine is installed on the Forward and Erga Mio, and features cooled EGR, a 2-stage turbocharger, and common rail system. In combination with a DPF, it complies with the post new long-term regulations and, except for certain models, achieves the 2015 fuel economy standards [7].

2. 2. 7. Isuzu 6HK1

Also available on the Forward and Erga Mio, the 6HK1 engine features cooled EGR, a variable geometry system (VGS) turbocharger, and common rail system. In combination with a DPF and SCR, it complies with the post new long-term regulations and, except for certain models, achieves the 2015 fuel economy standards [8].

Fig. 4 Isuzu 4HK1.

3 Engine Trends outside Japan

3. 1. Overview

3. 1. 1. Diesel engines for passenger vehicles

Continuing on from 2011, new engines were announced and launched in Europe mainly in compliance with the Euro VI regulations. As Japanese automakers also announced and launched vehicles with new engines, these engines may be installed in passenger vehicles launched in Japan in the future, in addition to SUVs.

3. 1. 2. Diesel engines for commercial vehicles

In 2012, a number of commercial diesel engines were launched in Europe to comply with the Euro VI regulations. Automakers adopted different technical approaches to achieving compliance with emissions regulations, resulting in a variety of engine specifications for EGR (cooled, hot, and EGR-less), turbochargers (2-stage, VG, asymmetrical, wastegate (WG)), and after-treatment systems (with or without DPF).

In contrast, few new engines were launched in North America since automakers are already in compliance with the EPA 10 regulations.

3. 2. New engine characteristics (Table 2)

3. 2. 1. Fuji Heavy Industries EE20 (Fig. 5)

This engine is installed in the Legacy and other mod-

Table 2 Specifications of new engines announced and launched outside Japan in 2012.

Application	Manufacturer	Model	Combustion	Intake	Cylinders	Bore × stroke (mm)	Displacement (cc)	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)
Passenger vehicles	Fuji Heavy Industries	EE20	DI	TCI	H4	86×86	1 998	110/3 600	350/1 600–2 400
	Honda	i-DTEC	DI	TCI	L4	76×88	1 597	88/4 000	300/2 000
	Audi	3.0BITDI	DI	TCI	V6	83×91.4	2 967	230/3 900–4 500	650/1 450–2 800
	Daimler	OM651	DI	TCI	L4	83×99	2 143	125/3 600–4 200	350/1 600–3 200
Commercial vehicles	Daimler	OM470 OM936	DI DI	TCI TCI	L6 L6	125×145 110×135	10 677 7 698	315/1 800 260/2 200	2 100/1 100 1 400 /1 200–1 600
	Cummins	ISB4.5 ISB6.7 ISL9	DI DI DI	TCI TCI TCI	L4 L6 L6	107×124 107×124 114×144.5	4 460 6 690 8 849	155/2 300 229/2 300 295/2 000	800/1 500 1 100/1 500 1 700/1 400
	Iveco	Cursor11	DI	TCI	L6	128×144	11 118	358/1 900	2 250/—
	DAF	MX13	DI	TCI	L6	130×162	12 902	375/1 900	2 500/1 000–1 400
	MAN	D0836 D2066	DI DI	TCI TCI	L6 L6	108×125 120×155	6 871 10 518	250/2 300 294/1 800	1 250/1 200–1 800 1 900/930–1 400
	Scania	DC9 DC13	DI DI	TCI TCI	L5 L6	130×140 130×160	9 291 12 742	206/1 900 353/1 900	1 400/1 000–1 300 2 500/1 000–1 300
	Volvo	D13K	DI	TCI	L6	131×158	12 777	338/1 400–1 800	2 300/1 000–1 400

DI: direct injection, TCI: turbo intercooler, H4: horizontally opposed 4-cylinder, L4: inline 4-cylinder, L6: inline 6-cylinder, L5: inline 5-cylinder

Fig. 5 Fuji Heavy Industries EE20.

Fig. 6 Honda i-DTEC.

Fig. 7 Audi 3.0 BiTDI

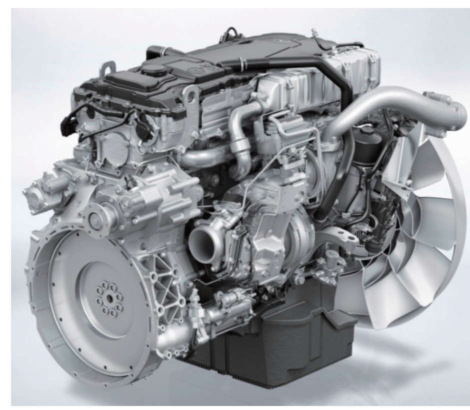

Fig. 8 Daimler OM 936.

els for the European market. It is a horizontally opposed diesel engine with a VG turbocharger and common rail system. In combination with a closed DPF, it complies with the Euro V regulations [9].

3. 2. 2. Honda i-DTEC (Fig. 6)

This engine is installed in the Civic and other models for the European market. It is the lightest engine in its class due to the adoption of an aluminum engine block. Featuring EGR, a VG turbocharger, and common rail system, this engine complies with the Euro VI regulations [10].

3. 2. 3. Audi 3.0 BiTDI (Fig. 7)

This engine features a twin turbocharger (high exhaust pressure side: electronically controlled VG turbocharger, low exhaust pressure side: WG turbocharger), 2,000 bar common rail system, and piezo injectors. It complies with the Euro V regulations [11].

3. 2. 4. Daimler OM 651

This engine features multiple EGR (high-pressure hot EGR: recirculation from the exhaust manifold to the intercooler outlet, low-pressure cooled EGR: recirculation from the DPF outlet to the turbocharger inlet), a common rail system, and piezo injectors. In combination with a DPF, it complies with the Euro VI regulations [12].

3. 2. 5. Daimler OM 470

This engine features cooled EGR and a common rail system, and is installed with a DPF and SCR. It also combines an asymmetrical turbocharger that optimizes and achieves top-class real-world fuel efficiency with an EGR system to comply with the Euro VI regulations [13].

3. 2. 6. Daimler OM 936 (Fig. 8)

This engine features cooled EGR, an asymmetrical turbocharger (high-power specifications: 2-stage turbocharger), common rail system, and variable valve timing. In combination with a DPF and SCR, it complies with the Euro VI regulations [14].

3. 2. 7. Cummins ISB4.5 and ISB6.7

These engines feature cooled EGR, a VG turbocharger, and common rail system. In combination with a DPF and SCR with high NOx conversion efficiency even at low exhaust gas temperatures, these engines comply with the Euro VI regulations [15].

3. 2. 8. Cummins ISL9

This engine features cooled EGR, a WG turbocharger,

Fig. 9 IVECO Cursor 11.

Fig. 10 MAN D0836.

and common rail system. In combination with a DPF and SCR with high NOx conversion efficiency even at low exhaust gas temperatures, it complies with the Euro VI regulations [16].

3. 2. 9. Iveco Cursor 11 (Fig. 9)

This is an EGR-less engine that features a VG turbocharger, common rail system, passive DPF regeneration, and a zeolite-based SCR system with high NOx conversion efficiency (95% or more). It complies with the Euro VI regulations [17].

3. 2. 10. DAF MX-13

This engine features EGR, a VG turbocharger, 2,500 bar common rail system, and a newly designed cylinder block. In combination with a DPF and DeNOx catalyst, it complies with the Euro VI regulations [18].

3. 2. 11. MAN D0836 (Fig. 10)

This engine features cooled EGR, a 2-stage turbocharger, and common rail system. In combination with a DPF and SCR, it complies with the Euro VI regulations [19].

3. 2. 12. MAN D2066

This engine features cooled EGR, a 2-stage turbocharger, and common rail system. In combination with a DPF and SCR, it complies with the Euro VI regulations [20].

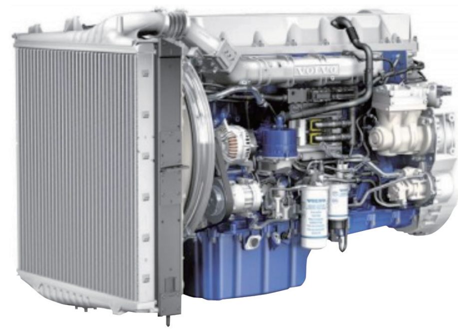

Fig. 11 Volvo D13K.

3. 2. 13. Scania DC9 and DC13

These engines feature cooled EGR, a VG turbocharger, unit injectors, and common rail system. In combination with a DPF and SCR, these engines comply with the Euro VI regulations [21].

3. 2. 14. Volvo D13K (Fig. 11)

This engine features hot EGR (EGR is mainly used to increase the temperature of the exhaust gas), a WG turbocharger, and unit injectors. In combination with a DPF and SCR, it complies with the Euro VI regulations [22].

4 Research and Development Trends

Development work for diesel engines is centered on compliance with increasingly stringent emissions regulations. In addition to cleaner emissions, the development of engines that also achieve better fuel efficiency and lower CO_2 emissions will accelerate further to meet customer, environmental, and regulatory requirements. This is likely to be the case for both passenger and commercial vehicles inside and outside Japan.

Specific trends for engines include the application and development of technology to improve thermal efficiency and to reduce engine loss. Examples include higher fuel injection pressures, combustion improvements, higher boost pressures, the optimization of turbochargers, the reduction of friction, and so on. As a result, it is likely that future engines will have even smaller displacements as well as lower engine speed and higher mean effective pressures. In addition, the development of fuel-saving idling stop mechanisms, controls to optimize engine speeds and accelerator opening angles, as well as controls that coordinate between the engine and vehicle, is likely to become more important.

Two main technical approaches to reducing emissions can be identified. The first involves suppressing engine-out gases and simplifying any components of the after-treatment system. The other involves simplifying the parts of the engine and enhancing the performance of the after-treatment system. The volume and ratio of engine-out NOx and PM is closely related to EGR and the development of key engine parts such as the turbocharger. After-treatment systems share development items that do not depend on the technological approach, such as the reduction of pressure loss for the whole system, the improvement of NOx conversion rates, and the like.

Currently, a wide range of slight improvements and modifications are being made to engine parts and after-treatment systems to comply with the direction of emissions regulations in each country. However, the number of engine suppliers following a strategy based on engine part modularization and commonization is likely to increase in the future as emissions regulations become harmonized and engine globalization continues.

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