Diesel Engines

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1) Mitsubishi Fuso Truck and Bus

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 CO2 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).

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

<table>
<thead>
<tr>
<th>Application</th>
<th>Manufacturer</th>
<th>Model</th>
<th>Combustion</th>
<th>Intake</th>
<th>Cylinders</th>
<th>Bore × stroke (mm)</th>
<th>Displacement (cc)</th>
<th>Maximum power (kW/rpm)</th>
<th>Maximum torque (Nm/rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger vehicles</td>
<td>Mazda</td>
<td>SH-VPTS</td>
<td>DI</td>
<td>TCI</td>
<td>L4</td>
<td>86 × 94.2</td>
<td>2 189</td>
<td>129/4 500</td>
<td>420/2 000</td>
</tr>
<tr>
<td></td>
<td>Mitsubishi</td>
<td>4N14</td>
<td>DI</td>
<td>TCI</td>
<td>L4</td>
<td>89 × 76.6</td>
<td>2 268</td>
<td>109/3 500</td>
<td>360/1 500</td>
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<tr>
<td>Commercial vehicles</td>
<td>Nissan</td>
<td>YD25DDTi</td>
<td>DI</td>
<td>TCI</td>
<td>L4</td>
<td>89 × 100</td>
<td>2 488</td>
<td>95/3 200</td>
<td>356/1 400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZD30DDTi</td>
<td>DI</td>
<td>TCI</td>
<td>L4</td>
<td>96 × 102</td>
<td>2 953</td>
<td>88/2 400</td>
<td>350/1 200</td>
</tr>
<tr>
<td></td>
<td>Hino</td>
<td>N04C</td>
<td>DI</td>
<td>TCI</td>
<td>L4</td>
<td>104 × 118</td>
<td>4 010</td>
<td>132/2 800</td>
<td>480/1 400</td>
</tr>
<tr>
<td></td>
<td>Isuzu</td>
<td>4HK1</td>
<td>DI</td>
<td>TCI</td>
<td>L4</td>
<td>115 × 125</td>
<td>5 193</td>
<td>177/2 400</td>
<td>756/1 600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6HK1</td>
<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>115 × 125</td>
<td>7 790</td>
<td>221/2 400</td>
<td>960/1 450</td>
</tr>
</tbody>
</table>

DE direct injection, TCI turbocharger intercooler, L4 inline 4-cylinder

Fig. 2 Mazda SH-VPTS.

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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. 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.

2.2.3. Nissan YD25DDTi (Fig. 3)

This engine is installed on the Nissan NV350 Caravan and the Isuzu Comio. 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.

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.

2.2.5. Hino N04C

Installed on the Dutro, this engine uses a new urea-
free 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 (6).

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-

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

<table>
<thead>
<tr>
<th>Application</th>
<th>Manufacturer</th>
<th>Model</th>
<th>Combustion</th>
<th>Intake</th>
<th>Cylinders</th>
<th>Bore × stroke (mm)</th>
<th>Displacement (cc)</th>
<th>Maximum power (kW/rpm)</th>
<th>Maximum torque (Nm/rpm)</th>
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<tr>
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<td>Fuji Heavy Industries</td>
<td>EE20</td>
<td>DI</td>
<td>TCI</td>
<td>H4</td>
<td>86 × 86</td>
<td>1 998</td>
<td>110/3,600</td>
<td>350/1,600-2,400</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Honda</td>
<td>i-DTEC</td>
<td>DI</td>
<td>TCI</td>
<td>L4</td>
<td>76 × 88</td>
<td>1 597</td>
<td>88/4,000</td>
<td>300/2,000</td>
</tr>
<tr>
<td></td>
<td>Audi</td>
<td>3.0BITDI</td>
<td>DI</td>
<td>TCI</td>
<td>V6</td>
<td>83 × 91.4</td>
<td>2 967</td>
<td>230/3,900-4,500</td>
<td>650/1,450-2,800</td>
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<td></td>
<td>Daimler</td>
<td>OM651</td>
<td>DI</td>
<td>TCI</td>
<td>L4</td>
<td>83 × 99</td>
<td>2 143</td>
<td>125/3,600-4,200</td>
<td>350/1,600-3,200</td>
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<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>125 × 145</td>
<td>10 677</td>
<td>315/1,800</td>
<td>2 100/1,100</td>
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<td></td>
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<td>OM936</td>
<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>110 × 135</td>
<td>7 698</td>
<td>260/2,200</td>
<td>1 400/1,200-1,600</td>
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<td></td>
<td>Cummins</td>
<td>JSB45</td>
<td>DI</td>
<td>TCI</td>
<td>L4</td>
<td>107 × 124</td>
<td>4 460</td>
<td>155/2,300</td>
<td>800/1,500</td>
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<td></td>
<td></td>
<td>JSB67</td>
<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>107 × 124</td>
<td>6 690</td>
<td>229/2,300</td>
<td>1 100/1,500</td>
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<td></td>
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<td>ISL9</td>
<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>114 × 144.5</td>
<td>8 849</td>
<td>295/2,000</td>
<td>1 700/1,400</td>
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<td></td>
<td>Iveco</td>
<td>Cursor1</td>
<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>128 × 144</td>
<td>11 118</td>
<td>358/1,900</td>
<td>2 250/-</td>
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<td></td>
<td>DAF</td>
<td>MX13</td>
<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>130 × 162</td>
<td>12 922</td>
<td>375/1,900</td>
<td>2 500/1,000-1,400</td>
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<td></td>
<td>MAN</td>
<td>D0836</td>
<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>108 × 125</td>
<td>6 871</td>
<td>250/2,300</td>
<td>1 250/1,200-1,800</td>
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<td></td>
<td></td>
<td>D2066</td>
<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>120 × 155</td>
<td>10 518</td>
<td>294/1,800</td>
<td>1 900-930-1,400</td>
</tr>
<tr>
<td></td>
<td>Scania</td>
<td>DC9</td>
<td>DI</td>
<td>TCI</td>
<td>L5</td>
<td>130 × 140</td>
<td>9 291</td>
<td>206/1,900</td>
<td>1 400/1,000-1,300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DC13</td>
<td>DI</td>
<td>TCI</td>
<td>L5</td>
<td>130 × 160</td>
<td>12 742</td>
<td>353/1,900</td>
<td>2 500/1,000-1,300</td>
</tr>
<tr>
<td></td>
<td>Volvo</td>
<td>D13K</td>
<td>DI</td>
<td>TCI</td>
<td>L6</td>
<td>131 × 158</td>
<td>12 777</td>
<td>338/1,400-1,800</td>
<td>2 300/1,000-1,400</td>
</tr>
</tbody>
</table>

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.  

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.  

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.  

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.

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.  

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.  

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.  

3.2.8. Cummins ISL9  
This engine features cooled EGR, a WG turbocharger,
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 \(^{(19)}\).

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 (65% 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 \(^{(20)}\).

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 commodization is likely to increase in the future as emissions regulations become harmonized and engine globalization continues.

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