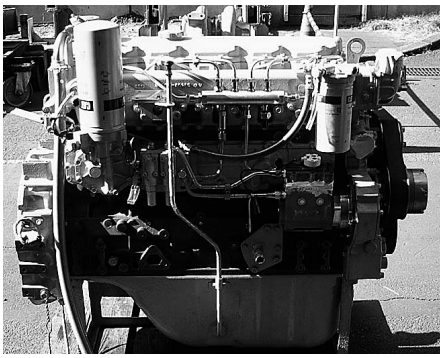

Eco-silent Combustion Technology of Environmental Engine

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1. Introduction

Mitsubishi heavy Industries, Ltd. (MHI) offers a wide variety of diesel engines ranging from 4 kW-class to 50 MW-class with high thermal efficiency and outstanding economic performance to support social infrastructures. Recently environmental problems such as global warming caused by CO_2, acid deposition caused by nitrogen oxides (NOx), photochemical oxidants, etc. are becoming social problems, calling strongly for high efficiency and prevention of exhaust emissions from industrial machines including automobiles. Especially, diesel engine involves the problem of particulate matter (PM) in addition to NOx. MHI promotes research and development of environmental engines conforming to the exhaust gas and noise regulations.

This paper describes the low-pollution and low-noise combustion technology for newly developed 50 kW-class to 2 MW-class industrial diesel engines to respond to the environmental regulations getting more and more severe. The new combustion technology will hereafter be called Eco-silent Combustion Technology(Note).

(Note) Trade mark registration pending

2. Trend in exhaust emission standards and corresponding technologies

Exhaust emission standards are enforced according to the social and environmental situations in various countries including Japan, the USA and European countries. Environmental Protection Agency (EPA) in America introduced exhaust emission standards for nonroad diesel engines in 1996, with Tier2 exhaust emission standards currently under way. As shown in the example of exhaust emission standards schedules and values set by EPA in **Fig. 1**, the values are becoming stricter and stricter gradually(1-4).

As for the noise regulation, there is a European version directive (2000/14/EC) for the outdoor machines including construction machines, generators, etc. The regulated noise levels are lowered stage-wise, with the second-stage regulation expected to start in 2006. Mitsubishi diesel engines are widely used in the outdoor machines subject to regulation, so that the reduction in noise and vibration of the engine itself is required.

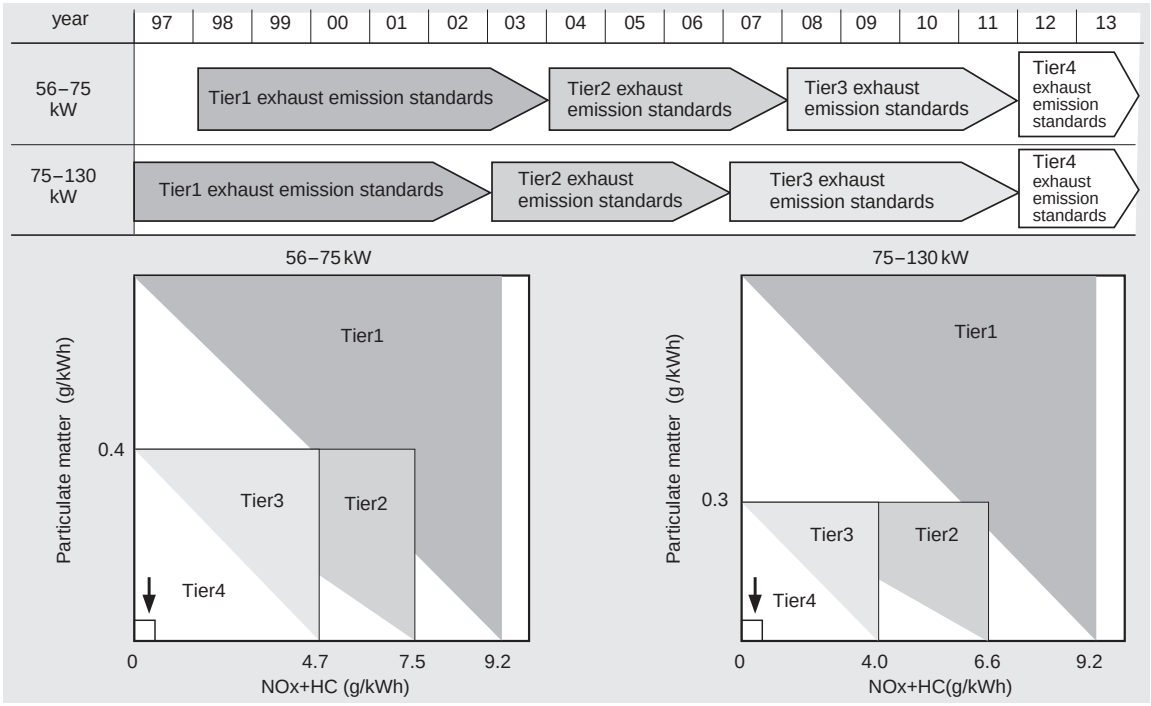

Fig. 1 EPA regulation scheduled and values for nonroad engine exhaust emission standards

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2.1 Eco-silent combustion technology

As a countermeasure against exhaust gas regulations, MHI has corresponded with retarded fuel injection timing, combustion optimization, and charge air cooling etc. to meet with Tier1 and Tier2 exhaust emission standards.

However, in order to meet with Tier3 exhaust emission standards to be introduced step-wise in and after 2006, the electronically controlled high-pressure fuel injection system such as common rail fuel injection system, etc.[2] will be necessary. **Fig. 2** shows a conceptual diagram of the engine with common rail fuel injection system.

Eco-silent combustion is a combustion technology based on multi-stage injection of fuel. Part of the fuel is subjected to pilot injection in order to reduce the generation of NOx, and the post-injection followed after the main-injection reduces the generation of PM.

Fig. 3 shows the pattern of heat release rates at multi-stage fuel injection. Further, the ignition delay of main injection can be shortened by raising the gas temperature in the cylinder before ignition of main injection, preventing sharp rise of pressure inside the cylinder. This led to the reduction of combustion noise. Further, the multi-stage injection parameter was optimized using the design of experiment to adopt highly robust injection pattern.

Fig. 4 shows the example of exhaust emission reduction using multi-stage injection and the design of experiment. The combustion method using the aforesaid multi-stage injection was realized by using the common rail fuel injection system, which was quite difficult by using the conventional mechanical fuel injection system.

As a countermeasure against the Tier3 exhaust emission standards, a good prospect could be obtained to sum up the engine specifications without having to use external Exhaust Gas Recirculation (EGR). This provides space allowance while mounting the engines on construction machines, ensuring substantial freedom (or allowance) in the layout and maintenance of the machines.

2.2 Simulation technology

It is important to know the states of flow and combustion inside the cylinder in order to reduce the exhaust gas. Intake and exhaust flow analysis and three-dimensional combustion analysis, etc. are counted as analytical tools for improving the engine combustion performance.

In the case of intake and exhaust flow analysis, intake flow analysis was carried out at the cylinder head intake port while combustion analysis was carried out inside the cylinder to estimate the combustion performance. An example of intake flow analysis is shown in **Fig. 5**.

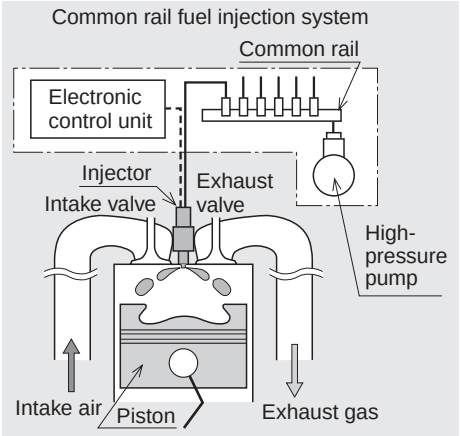

Fig. 2 Conceptual diagram of engine with common rail fuel injection system

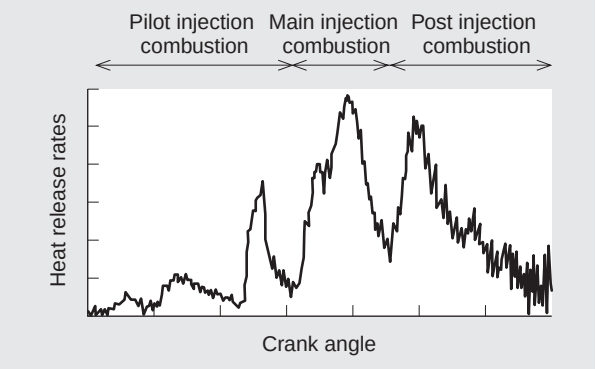

Fig. 3 Heat release rates pattern at multi-stage fuel injection

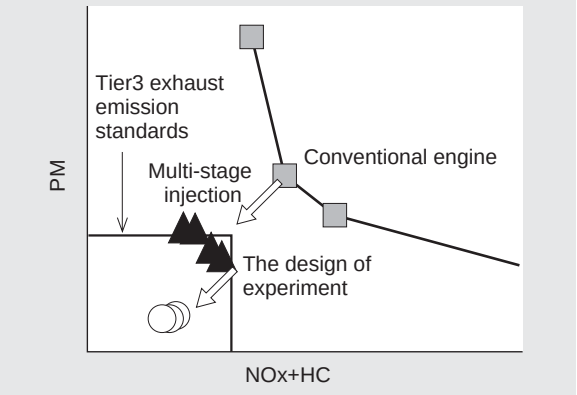

Fig. 4 Example of exhaust emission reduction using multi-stage fuel injection and the design of experiment

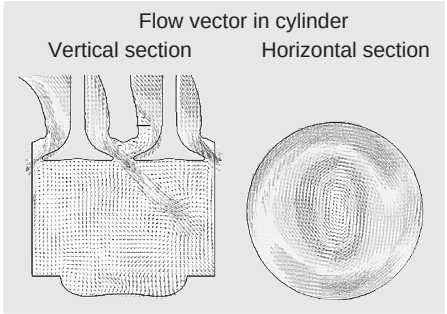

Fig. 5 Example of simulation analysis

3. Conclusions

MHI has started preparations for production to comply with Tier3 exhaust emission standards and European version regulations for noise.

Nevertheless, EPA Tier4 exhaust emission standards scheduled to be enforced in and after 2011 are expected to be extremely severe, with the values being roughly equivalent to one-tenth of the ones in Tier3 exhaust emission standards, requiring overall countermeasures against exhaust gas including after treatment equipment in addition to the engine itself. MHI is determined to make effective use of its wide range of technologies in development of products, and to contribute to the society through environmental-conscious diesel engines with high thermal efficiency.

The development of multi-stage fuel injection technology reported in this paper was conducted as part of a technical development project carried out by the Petroleum Energy Center (PEC) and subsidized by the Ministry of Economy, Trade and Industry of Japan. MHI would like to express its deep appreciation to all concerned people for their cooperation and support in the accomplishment of this program.

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