

Study of Diesel Engine System for Hybrid Vehicles

Tomomi Yamada, Hiroyuki Haga, Isao Matsumoto, and Terutoshi Tomoda
Toyota Motor Corporation

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ABSTRACT

In this study, we combined a diesel engine with the Toyota Hybrid System (THS). Utilizing the functions of the THS, reducing engine friction, lowering the compression ratio, and adopting a low pressure loop exhaust gas recirculation system (LPL-EGR) were examined to achieve both low fuel consumption and low nitrogen oxides (NO_x) emissions over a wide operating range. After applying this system to a test vehicle it was verified that the fuel economy greatly surpassed that of a conventional diesel engine vehicle and that NO_x emissions could be reduced below the value specified in the Euro 6 regulations without DeNO_x catalysts.

1. BACKGROUND OF RESEARCH

Recent years have seen growing demand for lower fuel consumption and cleaner exhaust emissions to help address environmental problems such as global warming and air pollution, and energy resource problems. Regulations concerning NO_x and other components of exhaust gas emissions are becoming even more stringent, and there are also plans in the near future to enforce strict controls on CO₂ as well in the world.

This research combined a diesel engine, which has greater potential for good fuel economy, with the THS. The synergy effect of fuel economy improvement in the diesel engine itself was examined. The aim was to achieve the low CO₂ emissions, not only during driving in urban areas, but also during highway driving at high speeds. Furthermore, the THS was utilized to reduce the level of exhaust gas emissions, which are an issue for diesel engines, as well as to reduce the cost of exhaust gas after treatment devices.

Figure 1 shows the trends for CO₂ emissions that are produced depending on vehicle weight. The specific targets for the diesel engine were an average thermal efficiency of 42 %, which is equivalent to 90 g of CO₂/km and top of the D-segment class shown in the figure, and also to achieve the Euro 6 levels for exhaust gas emissions without DeNO_x catalysts in the New European Driving Cycle (NEDC).

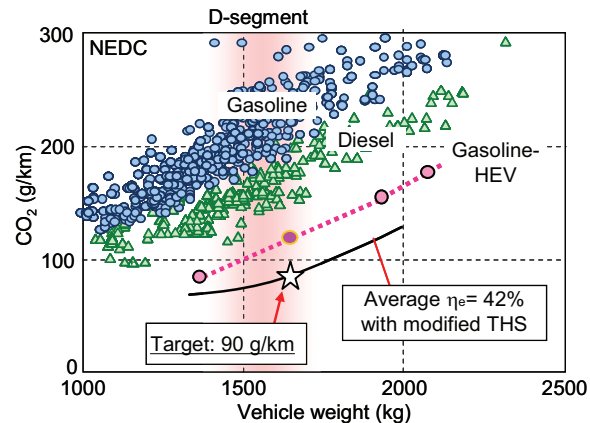


Fig. 1 Target of this study

2. CONCEPT OF DIESEL ENGINE FOR USE WITH THS

2.1. ISSUES FOR COMBINING DIESEL ENGINE WITH THS

The base diesel engine was a 2.2 liter, 4-cylinder shown in Fig. 2 and Table 1. A diagram of the power train system configuration is shown in Fig. 3. The THS has the following three functions to enhance engine efficiency: (1) automatic stopping of the engine during electric vehicle (EV) running and when the

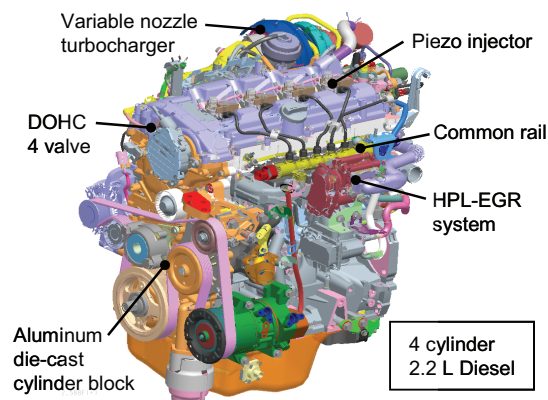


Fig. 2 3D drawing of base engine

vehicle is stopped and idling, (2) recovery of kinetic energy during deceleration, and (3) control of the operating range of the engine (this is referred to as the electric CVT function) [1]. The electric CVT is a function that selects the most efficient operating range by controlling the engine speed with electric motor. However, a conventional diesel engine has high NOx emissions in the high load range where fuel economy is good. In addition, since diesel engines are lean burning combustion engines, they cannot utilize three-way catalysts like a gasoline engine [2]. Therefore, the electric CVT function of the THS cannot be utilized to its full advantage, since it is necessary to select the low load range in that both thermal efficiency and NOx emissions are low. If high load range is selected for better thermal efficiency, a cost of the system becomes higher by adopting DeNOx after treatment devices such as selective catalytic reduction (SCR) system or NOx storage and reduction (NSR) system. Therefore, the aim of the research was set to resolve this issue by constructing a diesel engine suitable for use with the THS.

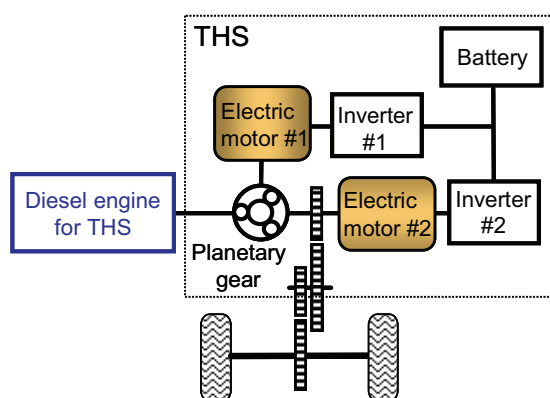


Fig. 3 Configuration of power train system

2.2. DIESEL ENGINE CONCEPT FOR THS

In order to achieve the aim, we have taken a following approach in designing of a diesel engine system: (a) to expand the low fuel consumption range to the low load area by lowering engine friction and (b) to expand the low NOx range to the high load area by adopting a low compression ratio and LPL-EGR. The configuration of the experimental engine system is shown in Fig. 4 and the engine specifications are shown in Table 1.

Furthermore, high aspect ratio combustion chambers were adopted in order to improve thermal efficiency by reducing soot emissions especially at high EGR rate combustion. Aspect ratio was defined as the ratio of combustion chamber diameter to its depth. A schematic drawing of the combustion chamber is shown in Fig. 5.

The main technologies are described in detail below.

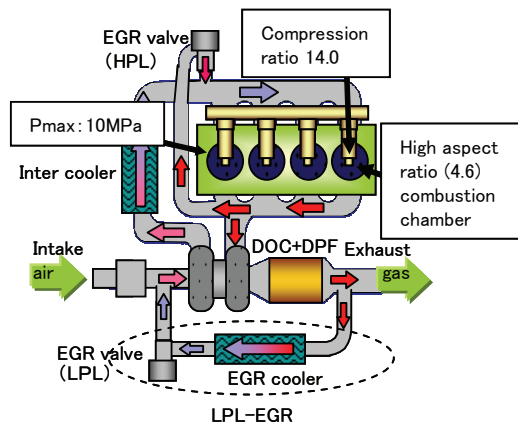


Fig. 4 Configuration of the experimental engine

Table 1 Engine specifications

	Base engine	Experimental engine
Type	Inline 4 DI	←
Bore (mm)	86	←
Stroke (mm)	96	←
Displacement (cm ³)	2231	←
Compression ratio	15.7	14.0
Max. cylinder pressure (MPa)	15	10
Main journal diameter (mm)	59	57
Crank journal diameter (mm)	50	42
Piston pin diameter (mm)	29	22
Total weight of moving parts (g/cyl)	1626	999
EGR system	HPL	HPL+LPL
Belt system	Serpentine	Beltless

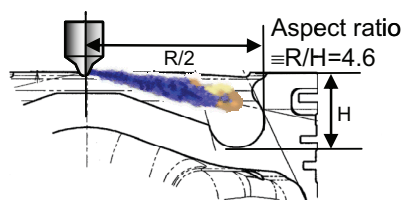


Fig. 5 Schematic drawing of high aspect ratio combustion chamber

2.3. REDUCING FRICTION BY LOWERING P_{MAX}

A diesel engine is designed to withstand a high maximum cylinder pressure (P_{max}) to ensure power under a high compression ratio and supercharging. Therefore, the shaft bearings are large and the weight of the moving parts is increased, which increases the friction and causes the fuel economy to deteriorate.

In contrast, the THS is equipped with a battery and electric motor that provide a drive power assistance function, which means it is possible to reduce the power of the engine. In this research, the power of the engine was reduced by 20 kW compared to the base engine power of 130 kW. The simulated results for P_{max} sensitivity in relation to engine output are shown in Fig. 6. The higher compression ratio of the engine, the higher sensitivity is because its power is limited due to P_{max} that is restrained by not only retarded combustion timing but also lowered supercharging pressure. On the contrary, lower compression ratio, explained in detail below, is advantageous to attain the required power with lower