

Summary and Progress of the Hydrogen ICE Truck Development Project

Atsuhiko Kawamura, Tadanori Yanai and Yoshio Sato
National Traffic Safety and Environment Laboratory

Kaname Naganuma, Kimitaka Yamane and Yasuo Takagi
Musashi Institute of Technology

Copyright © 2009 SAE International

ABSTRACT

A development project for a hydrogen internal combustion engine (ICE) system for trucks supporting Japanese freightage has been promoted as a candidate for use in future vehicles that meet ultra-low emission and anti-global warming targets. This project aims to develop a hydrogen ICE truck that can handle the same freight as existing trucks. The core development technologies for this project are a direct-injection (DI) hydrogen ICE system and a liquid hydrogen tank system which has a liquid hydrogen pump built-in. In the first phase of the project, efforts were made to develop the DI hydrogen ICE system.

Over the past three years, the following results have been obtained:

- A high-pressure hydrogen gas direct injector developed for this project was applied to a single-cylinder hydrogen ICE and the indicated mean effective pressure (IMEP) corresponding to a power output of 147 kW in a 6-cylinder hydrogen ICE was confirmed. In addition, nitrogen oxide (NO_x) was reduced with a high thermal efficiency by the optimization of the EGR ratio, the injection timing and the ignition timing. From these results, a DI multi-cylinder hydrogen ICE using this injector was concluded to be highly feasible.
- A NO_x storage-reduction (NSR) catalyst system was applied to the hydrogen ICE. We confirmed that the NO_x conversion rate was high and the fuel penalty was low under the limited conditions.

INTRODUCTION

Railroads and coastal shipping have historically been the primary methods for domestic distribution in Japan. Currently, 91% of shipping (by weight) uses trucks due to their economy and convenience. Thus, truck freight occupies a large role in Japanese economic activities. The crude oil equivalent energy consumption of the Japanese transportation sector in 2006 was 3,751 PJ, equal to 24% of total consumption. Two major groups, passenger cars (1,932 PJ) and freight trucks (1,331 PJ), accounted for 87% of transportation sector consumption. Until recently, exhaust gas emission control in the form of large reductions in particulate matter (PM) and nitrogen oxide (NO_x) has been demanded from the transportation sector. In recent years, the demand has shifted to large reductions of carbon dioxide (CO_2) for the purpose of global warming prevention. In conjunction with these demands, electricity and hydrogen, which do not emit CO_2 during consumption, have attracted attention as energy sources for future vehicles. Encouraged by this shifting emphasis, designers are developing passenger cars and shuttle buses that use a battery and a hydrogen fuel cell (FC). For small- or medium-sized trucks, diesel hybrid systems can be put into practical use. However, there is strong demand for a technology that can be applied to large-sized (heavy duty) trucks requiring a high specific output.

A hydrogen internal combustion engine (ICE) vehicle can utilize existing engine technologies already developed by the automotive industry. In addition, CO_2 -emission performance is expected to be near that of an

electric vehicle (EV) for the same specific output as existing vehicles. Thus, there are many examples of development leading the way to the hydrogen ICE vehicle [1, 2]. In addition, the hydrogen ICE system is also expected to match the specific output of existing diesel trucks.

The hydrogen ICE system is considered to be promising for large trucks in terms of global warming prevention. For the aforementioned reasons, the hydrogen ICE truck development project is promoted as one of the research and development objectives in the Next-generation Environmentally Friendly Vehicle Development and Commercialization Project (EFV21) of the Ministry of Land, Infrastructure, and Transport (MLIT) of Japan.

PURPOSE, SUMMARY, ITEM DEVELOPMENT, AND STRATEGY OF THE PROJECT

The particular problems of a hydrogen ICE vehicle arise from the properties of hydrogen itself. These include difficulty in obtaining a high output and low NO_x emissions from the engine as well as the difficulty of fuel deployment. This project aims to produce a hydrogen ICE truck with a non-loading vehicle weight and gross vehicle weight (GVW) equal to that of existing diesel trucks. The main development elements needed for this purpose are a high-output, low-NO_x hydrogen ICE system and an in-vehicle hydrogen tank system. These issues are addressed in the following sections.

Figure 1 shows a schematic of the development components of the project. The high-output, low-NO_x hydrogen ICE system mainly consists of a direct-injection (DI) hydrogen ICE system and a NO_x reduction catalyst system. The in-vehicle hydrogen tank system mainly consists of a liquid hydrogen tank system and a liquid hydrogen pump. This report describes the status of the development and progress of the high-output, low-NO_x hydrogen ICE system, which is placed with the first development element in the first period of this project.

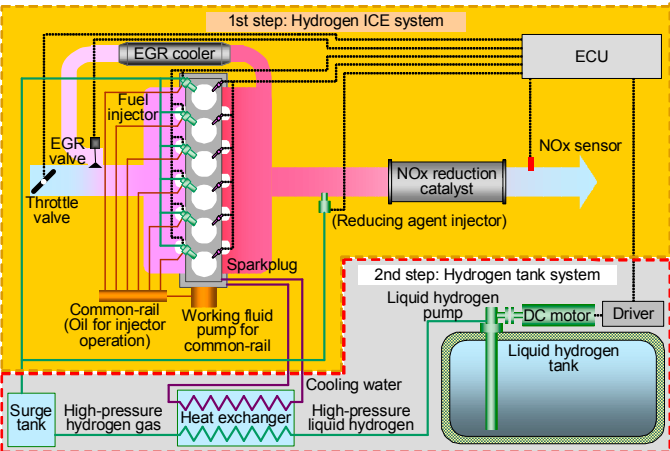


Figure 1: Development components of the project

The development target of the high-output, low-NO_x hydrogen ICE system will be realized as a high-performance hydrogen ICE system with specific output and fuel consumption equal to a mass-produced diesel engine for trucks and with an ultra-low NO_x emission of less than one fourth of the New Long-term Emission Regulatory Requirements of Japan. In this project, which aims for an application to medium duty trucks with a GVW of eight tons, we plan to remodel the base engine into a hydrogen ICE. The base engine is a mass-produced, 7.7 L, 6-cylinder, naturally aspirated (NA) diesel engine (HINO J08). The main remodeling of the base engine involves a reduction of the compression-ratio through the addition of a mechanism to the piston and the addition of a sparkplug. The specifications of the target hydrogen ICE are shown in Table 1. The performance targets of this project using this engine with the NO_x reduction catalyst system are shown in Table 2.

Table 1: Specifications of target hydrogen ICE

Item	Specification
Base engine	Hino J08
Engine type	4-cycle inline 6-cylinder
Cooling system	Water cooled
No. of valves	4 valves
Engine displacement	7.684 L
Bore × Stroke	112 mm × 130 mm
Compression ratio	13 : 1
Fuel	Hydrogen gas
Injector	Injection type: Direct injection Hole type: Multi holes Max. injection pressure: 20 MPa
EGR system	Water cooled EGR
Ignition system	Spark ignition
Aspiration	Naturally aspirated (NA)

Table 2: Performance targets of the project

Item	Target performance
Output power	147 kW @3,000 rpm, NA (IMEP: 0.85 MPa)
Fuel economy	The same level of base engine
Emission	NO _x : Less than 0.5 g/kWh by JE05 drive mode (Less than 1/4 of the New Long-term Regulation) PM: Near zero level CO ₂ /CO/HC: Near zero level

A strategy to approach the performance targets begins with the performance of the multi-port injection (MPI) hydrogen ICE, as shown in Figure 2. Because the output power largely decreases from that of the base engine at this point, recovery of the output power by DI is planned. The problem of an increase in NO_x occurring at the same time was resolved by optimizing the exhaust gas recirculation (EGR), fuel injection timing, spark ignition timing, and the NO_x reduction catalyst system.

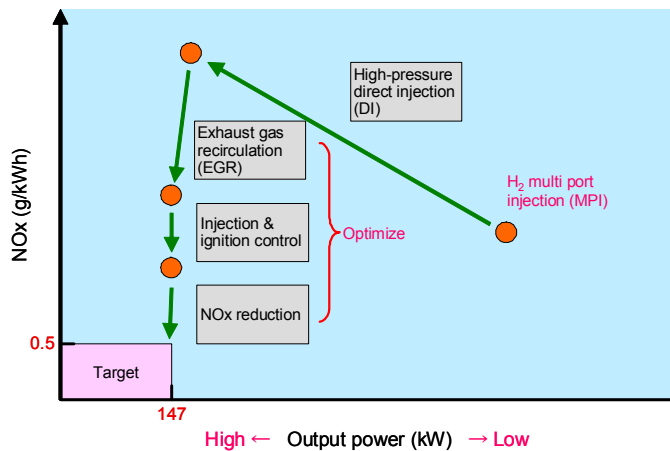


Figure 2: Strategy for approaching performance targets

DEVELOPMENT PROGRESS FOR THE HIGH-OUTPUT, LOW-NO_x HYDROGEN ENGINE SYSTEM

The core development technologies for realizing this system are a high-pressure hydrogen gas direct injector and a NO_x reduction catalyst system. The details, development progress, measured results, and general assessments are presented below.

HIGH-PRESSURE HYDROGEN GAS DIRECT INJECTOR

The high-pressure hydrogen gas direct injector developed in this project is shown in Figure 3. This injector was based on a common-rail type direct injector for the base diesel engine, thus maintaining installation compatibility. The opening and closing of the needle valve are performed by controlling the spill amount of a working fluid (diesel oil) supplied from a common-rail by the timing of an electromagnetic valve [3]. Non-fuel will be used for the working fluid in the future. The hydrogen gas is supplied with at most 20 MPa to maintain its independence from the flow of the working fluid. Thus, this injector aims at the high-speed response needed for multi-injection in the future.

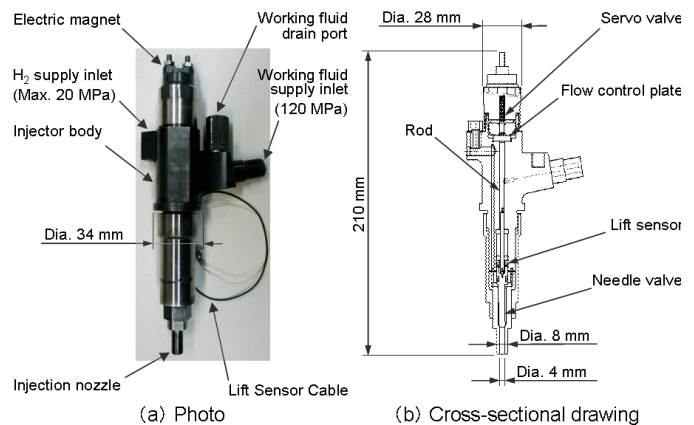


Figure 3: Common-rail type high-pressure hydrogen gas direct injector

The injection characteristics of this injector are shown in Figure 4. The injector injected 400 mL of hydrogen gas at standard temperature and pressure (STP) with an actual injection time of 2.1 msec (at a crank angle of 40 degrees) and an engine speed of 3,000 rpm. Although not shown in the figure, the hydrogen gas leak from the tip of the needle valve was less than 100 mL (STP)/min.

This injector was applied to the DI single-cylinder hydrogen ICE, and the power output and NO_x emissions were estimated. The specifications of the DI single-cylinder hydrogen ICE are shown in Table 3, and the combustion chamber configuration is shown in Figure 5. The bore, stroke, and compression ratio that govern engine performance are approximately the same as for the target engine, but the number of the valves and the placement of the injector and sparkplug are different from those of the target engine. Because the injector was placed at the edge of the combustion chamber, the nozzle hole was designed to discharge in the shape of a fan so that hydrogen gas was dispensed equally throughout the combustion chamber. In addition, the center electrode of the sparkplug was extended so that firing was performed in the vicinity of the nozzle hole on the injector. Because it was difficult to obtain a single-cylinder engine with specifications similar to those of the target engine, we chose this engine instead. When target performance is achieved in this engine, then the performance of the target engine, which has a well-shaped combustion chamber, will be realized in a satisfactory manner.