DEVELOPMENT PROJECT OF A HYDROGEN FUELLED INTERNAL COMBUSTION ENGINE FOR HEAVY DUTY TRUCK - OUTLINE AND PRELIMINARY TEST

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Abstract

The hydrogen fuelled internal combustion engine represent a promising solution to the issues of global warming, fossil fuel break point and environmental protection. The development of a hydrogen fuelled internal combustion engine for heavy-duty truck has been being carried out at Hydrogen Energy Research Centre (HERC) of Musashi Institute of Technology and National Traffic Safety and Environment Laboratory (NTSEL) since FY 2005 in the Next-Generation, Low-Emission Vehicle Development - Practical Implementation Project (EFV21) of Ministry of Land, Infrastructure and Transport (MLIT). As the most important key technology, the development of the common-rail type electronic high pressure hydrogen injectors is performed. Now the development of a hydrogen fuelled engine with 6 cylinders, the total displacement of 7.7 litters, direct injection and spark ignition is about to start. In this paper, the development concept, the characteristics of the injectors, some performance in the engine output power and the effects of NOx reduction catalyst ever obtained experimentally by using a single cylinder engine are demonstrated.

Keywords: *Combustion Engine, Hydrogen Engine, Direct Injection, NOx Emission, NOx Reduction Catalyst*

1. Introduction

It is well understood that vehicles are the necessities of life even in future and fossil fuel is subject to generation of carbon dioxide that is the most contributory gas of the global warming effects. Burning hydrogen, however, generates completely no carbon dioxide so that hydrogen has been being expected to be a fuel in future.

The hydrogen can be produced artificially and unlimitedly by solar energy and water as a renewable energy. The combustion product is only water in general, some thermal nitrogen oxides occur in a special case owing to the high temperature of the combustion.

The only task remained now is to obtain hydrogen at cheaper price than that of conventional fuel. The price of hydrogen will become relative cheaper in future.

Lightness, compactness and large output power of power sources are mandatory even if the power sources are superior in the other things such as thermal efficiency, low noise and the like. However, the vehicles powered by fuel cell engines (FCV) are electric cars so that the FCV is inferior in those respects. FCV is too expensive for us to have them as vehicles. FCV is vulnerable to severe surroundings such as cold temperature, strong wind with seawater mist, air with very small hydrogen sulphides in volcanic places and the surroundings where a fire takes place.

Trucks are subject to moving things, for that reason, the above necessities are much more important. Direct injection hydrogen engines are the best among hydrogen engines, especially in the output power. In addition, clean hydrogen fuelled engines can be surely put into practice in place of diesel ones for truck use.

To overcome the depletion problem and the environmental one for fossil fuel in future, a hydrogen fuelled engine with 6 cylinders, the total displacement of 7.7 litters, direct injection and spark ignition for heavy duty truck use has been being developed in the Next-Generation, Low-Emission Vehicle Development - Practical Implementation Project (EFV21) by the Ministry of Land, Infrastructure, and Transport and National Traffic Safety and Environment Laboratory (NTSEL) [1].

2. Development targets and the means

The aim is to develop a hydrogen fuelled direct injection engine with the maximum output power of 147 kW, 0.5 g/kWh NOx emission, almost zero HC, PM and CO_2 emission when the engine runs on the test mode of JE−05 emission test and the fuel consumption is the same of that of the original diesel engine on the calorific basis as shown in Table 1. Figure 1 shows the development scheme. In order to increase the output power, a hydrogen direct injection into the combustion chamber at high pressure during the compression stroke is to be adopted. When the direct injection is used, the output power about 2.3 times as large as that of the port injection can be theoretically obtained.

Tab. 1. Development Targets

Maximum Output Power		147 kW
Exhaust Emission*		*JE-05 Emission Test Mode
	NOx	0.5 g/kWh
	HC	Almost Zero
	CO	Almost Zero
	CO_2	Almost Zero
Fuel Consumption		The same as that of Diesel Engine (Calorific Base)

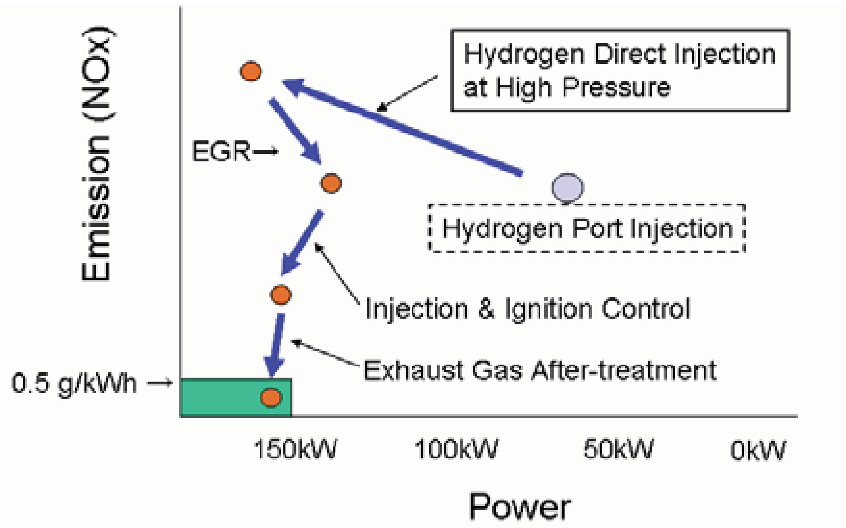

Fig. 1. Development Scheme for High Output Power and Near-Zero Emission

Thanks to the heterogeneous combustion of the direct injection, the NOx emission is smaller than the homogeneous combustion of the port injection in high output engine operation. To further decrease the NOx emission to the near-zero emission, an exhaust gas recirculation (EGR), injection and ignition timing control and exhaust gas after-treatment are also to be adopted.

3. Hydrogen Fuelled Direct Injection Engine

The original diesel engine is a four-stroke, water-cooled, turbo-charged, engine of Hino Motor J08E-TI model with 6 cylinders, the total displacement of 7.7 litters, the common-rail type fuel supply system and the electronic engine control unit. Every device installed in the engine is operated electronically through the engine control unit.

Table 2 shows the comparison of the original diesel engine and the hydrogen fuelled engine specifications. Owing to changing the air charging system from turbo-charging to naturally aspirated form, the maximum output power of the hydrogen fuelled engine is decreased. The compression ignition is difficult to ignite the injected hydrogen so that the compression ignition system is changed to the spark ignition one. The compression ratio is decreased from 18 to 13 because the experimental data showed the compression ratio of 13 was the best for the same type of hydrogen fuelled engines.

To achieve the targets, the hydrogen fuelled engine is to be controlled electronically by the engine control unit. The outline of the hydrogen fuelled engine system developed now is schematically shown in Figure 2.

Tab. 2. Comparison in Engine Specifications between Original Diesel Engine and Hydrogen Fuelled Engine

Item	Original	Hydrogen
Engine Type	4-stroke, Water-cooled, 6-cylinder, 4-valve/cylinder	⟵
Fuel	Diesel Fuel	Hydrogen
Max. Output Power	177 kW	147 kW
Air Charging System	Turbocharging	Naturally Aspirated
Total Displacement	7.684 liters	⟵
Bore x Stroke	112 x 130 mm	⟵
Combustion Chamber	Reentrant Bowl	Dog Dish
Ignition System	Compression Ignition	Spark Ignition
Injection System	Common-rail Type Multi-Hole Nozzle	⟵
Compression Ratio	18.0	13.0

The each cylinder has a hydrogen injector and a spark plug which are controlled electronically by the engine control unit. The intake manifold has a throttle valve which is usually kept open fully. And the exhaust manifold has a NOx-Storage-Reduction (NSR) catalyst to decrease further the NOx emission in the exhaust gas.

4. Development and Preliminary Test results

On the way of this engine development, some devices such as the hydrogen injectors and the NOx-Storage-Reduction catalyst were experimentally made to know whether the performances were satisfactory. These devices were installed on a single test engine and the engine ran in firing. The following results were obtained.

4.1. Common-rail Type High Pressure Hydrogen Gas Injector

In order to achieve the high output power as diesel engines, the high thermal efficiency also like the diesel engines and the near-zero emission simultaneously, precise injection control is required.

The common-rail type high pressure hydrogen gas injector developed here is electronically operated so that the control is definitely precise. Figure 3 shows the injector developed by making a good use of a diesel engine common-rail type injector. The injector injects hydrogen gas at the ambient temperature and the injection pressure of 20 MPa.

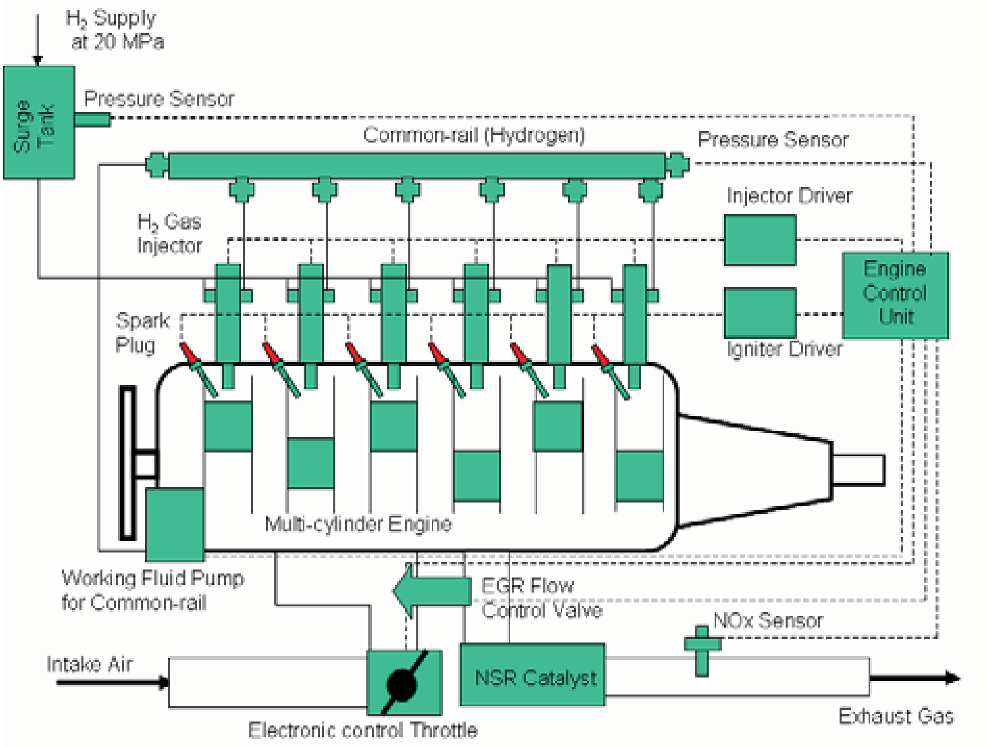

Fig. 2. Outline of the Hydrogen Fuelled Engine System

The injector is operated by the common-rail system originally developed for diesel engines. The injector was operated to obtain the quantity of hydrogen gas per a single injection as shown in Figure 4, in the three cases of the injection frequency of 4.2 Hz equivalent of 500 rpm engine revolution, 8.3 Hz equivalent of 1000 rpm engine revolution and 25 Hz equivalent of 1500 rpm engine revolution. It is found that the three cases of the injection frequency have almost the same quantity of hydrogen gas per a single injection and that it took 1.37 milli-second to inject out 400 Nml of hydrogen per a single injection. Namely, it needed 49 degrees crank angle at 3000 rpm to inject out 400 Nml of hydrogen per a single injection.

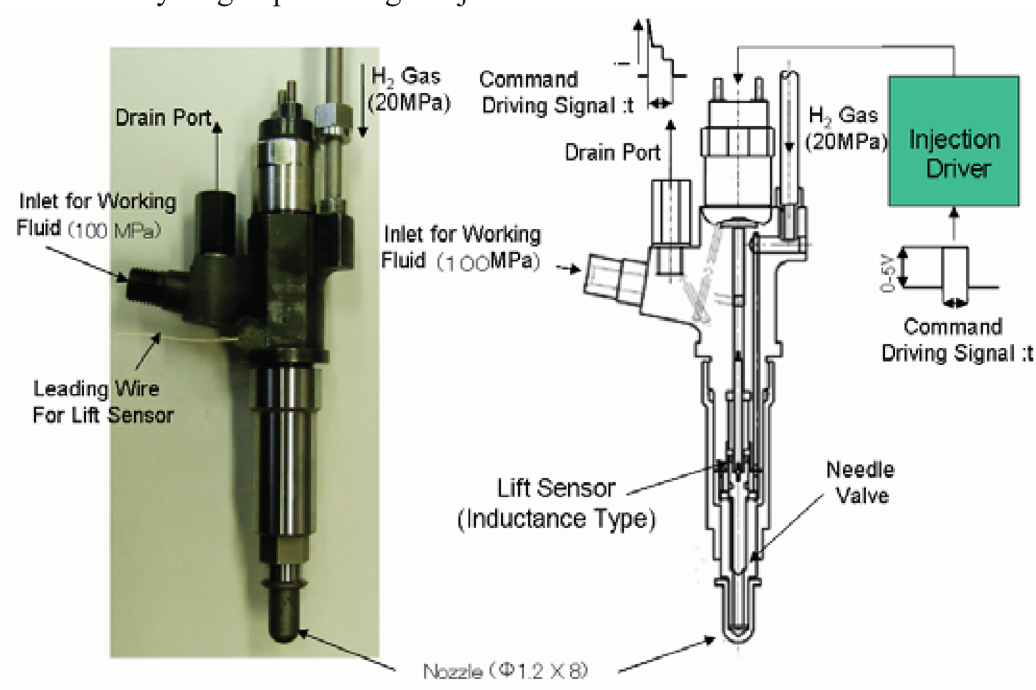

Fig. 3. Common-Rail Type High Pressure Hydrogen Gas Injector

4.2. Initial Operation Test of Injector

To study the integrity of the common-rail type high pressure hydrogen gas injector developed for the 6 cylinder engine shown in Table 2, the injector was installed in the engine head and the engine ran in firing by using the injector to confirm whether it could stand the thermal load on the engine operation. The test engine is a single cylinder, water cooled, two-valve, and naturally aspirated engine with the specifications shown in Table 3.

Tab. 3. Specifications of Single Cylinder Engine

Engine Type	4-stroke, Water-cooled, Single Cylinder, 2-valve/cylinder
Fuel	Hydrogen
Air Charging System	Naturally Aspirated
Injection System	Common-rail Type Multi-Hole Nozzle
Ignition System	Spark Ignition
Total Displacement	1.053 Liters
Bore x Stroke	108 x 115
Compression Ratio	13
Combustion Chamber	Dog Dish
Swirl Ratio	2.2

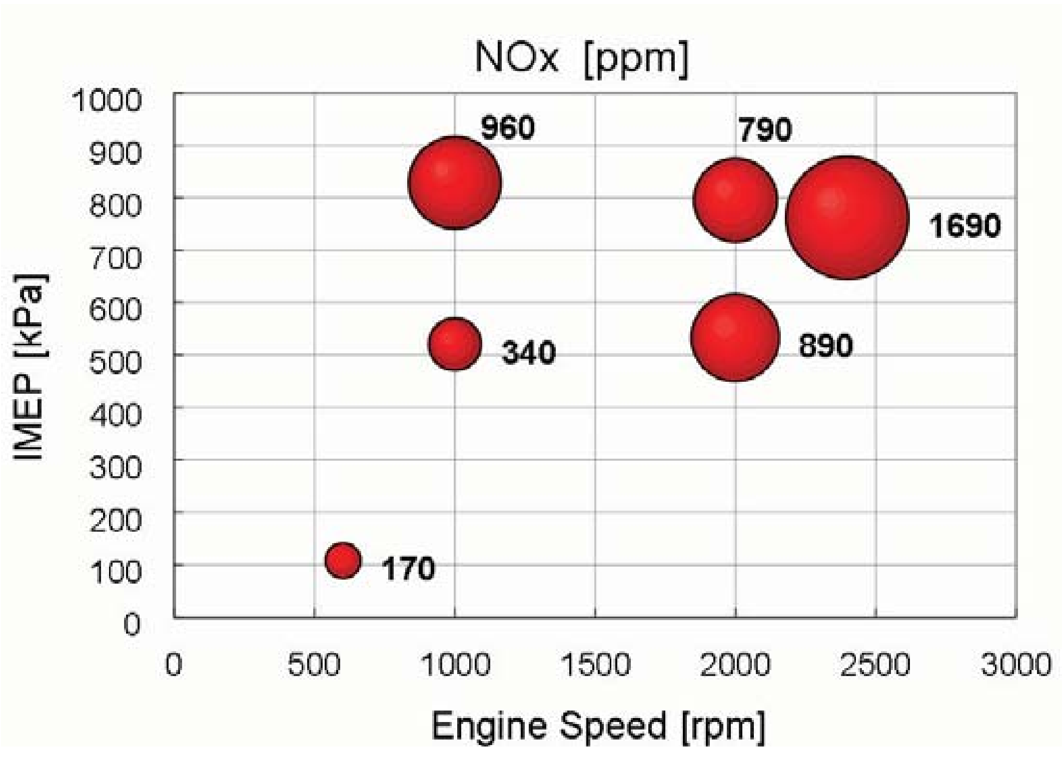

Fig. 4. Injection Quantity vs. Command Driving Signal Time

The injector was used in collecting the engine data five times an experiment for about four hours. Namely, the total running time was about twenty hours. After the experiment, the injector was disassembled to inspect the integrity. No problem was found. Figure 5 shows the engine speed vs. the indicated mean effective pressure IMEP graph. The size of the red ball in the graph represents the amount of NOx emission concentration measured in the exhaust gas at the engine exhaust port of the engine head. The figure beside the ball shows the value of NOx concentration. It is found in this figure that the maximum IMEP was 800 kPa, which implies that the 6-cylinder hydrogen fuelled engine shown in Table 2 may produce the maximum output power of 147 kW. The NOx concentration measured were found reasonable when the injection took place in the late part of the compression stroke.

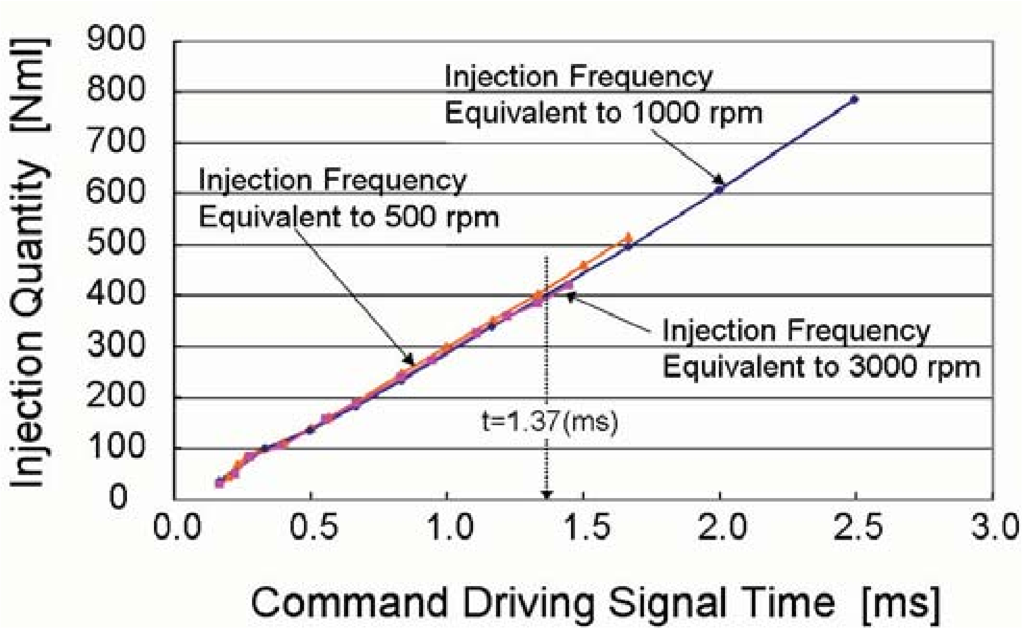

Fig. 5. NOx Emission Concentration in Single Cylinder Engine Test

Conversion Efficiency Test of NOx Storage Reduction Catalyst

To further decrease the NOx emission to the near-zero level, a NOx-Storage-Reduction (NSR) catalyst is required. As there were two types of the catalyst A and B available as shown in Fig. 6, a comparison of the NOx conversion efficiency was made between the two types by measuring the NOx concentration in the exhaust gas of the single cylinder engine at the inlet and the outlet of the catalysts while varying the temperature at the inlet of the catalysts. As shown in Fig. 7, it was found that the catalyst B had a little wider range of the active temperature in the NOx conversion efficiency.

Tab. 6. Tested NOx Storage Reduction Catalyst

(a) Tested Catalyst for Single Cylinder Engine

Catalyst	Component	Size; D × L	Volume
A	Pt / Rh=3:1	144mm × 152mm	2.47 liter
B	Pt / Pd=3:1	144mm × 152mm	2.47 liter

(b) Tested Catalyst A, B

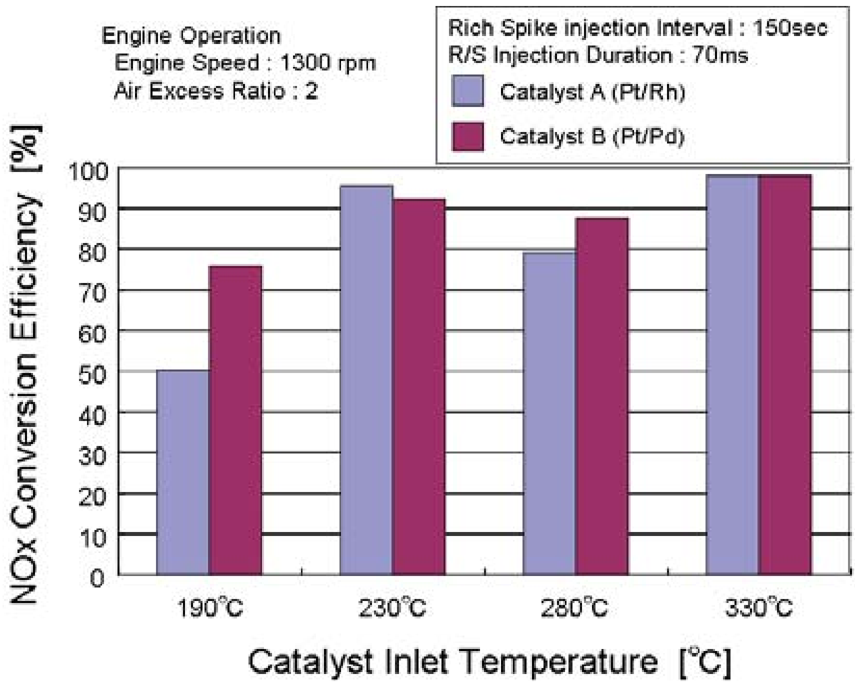

Fig. 7. Test Results of NOx Conversion Efficiency

Summary

The development and preliminary test initial of the component such as the common-rail type high pressure hydrogen injectors and the NSR catalyst have been finished. Now, the 6-cylinder original diesel engine has been placed on the engine bench to be modified to the hydrogen fuelled engine. The firing test of hydrogen fuelled engine will be expectedly carried out in this year.

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