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PROCEEDING

The 4th International Conference on Education, Concept, and Application of Green Technology 2015

Grand Candi Hotel
Semarang, Central Java, Indonesia
September 10th, 2015

UNNES
UNIVERSITAS NEGERI SEMARANG

ENGINEERING FACULTY
SEMARANG STATE UNIVERSITY

EIC
Engineering International Committee

ARCHIEVE DETAIL

The 4th Conference

Green technology has been an inspiration for Research and Development in the World. It's the application of one or more of environmental science, green chemistry, environmental monitoring and electronic devices to monitor, model and conserve the natural environment and resources, and to curb the negative impacts of human involvement. The term is also used to describe sustainable energy generation technologies such as photovoltaics, wind turbines, bioreactors, renewable energy, thermo-fluids etc. Sustainable development is the core of environmental technologies. Based on the recent issue, Engineering International Committee which includes eight countries (Indonesia, Malaysia, Singapore, Taiwan, Australia, German, USA and Japan) conducts the international conference on education, concept, and application of green technology 2015. Delegates from university, industry, governmental or non-governmental organizations and capital providers may present their views on green technology.

Conference Day and Venue

Day : September 10th, 2015

Venue : Grand Candi Hotel Semarang

Invited Keynote Speakers

Professor Dr. Zainal Alimudin bin Zainal Alauddin

School of Mechanical Engineering, Universiti Sains Malaysia

Prof. Tatsuo Sawada

Department of Mechanical Engineering, Keio University

Prof. Kenji Takahashi, Ph.D

Graduate School of Natural Science and Technology, Kanazawa University

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Suitability of Conventional Fuel Injectors to be Used in Gasoline Direct Injection System for a Small Capacity Two-Stroke Engine

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***Abstract*—Gasoline Direct Injection (GDI) system could deliver superb performance enhancement if applied to two-stroke gasoline engines. The GDI's requirement for special components had been limiting its wider implementation. This research was carried out to study how far three types of injectors representing injectors available widely in the market were suitable to be used as GDI injector for small capacity two-stroke gasoline engines. Three potential injectors that had been investigated were a stationary Diesel injector, a piezoelectric Diesel injector, and a four-stroke gasoline injector. The suitability was evaluated based on the injector's fuel flow rates and response times. The piezoelectric Diesel injector qualified as GDI injector and can potentially be operated under stratified charging mode. The four-stroke gasoline injector qualified to be used as low-pressure GDI injector but can only be operated under homogeneous charging mode only at low engine speeds and small throttle openings.**

Keywords—injector, injector response time, fuel injection, GDI, two-stroke gasoline engine

I. Introduction

Scavenging process is both the good and the bad parts of a conventional two-stroke gasoline engine design. The presence of scavenging process makes two-stroke engine able to expel residual combustion gas out and admit fresh fuel-air mixture in to the combustion chamber on just one piston stroke. During that same scavenging process however, some of the fresh mixture got carried away to the exhaust manifold and thus making the engine's fuel consumption and emission characteristics worse than its four-stroke counterpart.

The advancement of electronic fuel injection technology had led to the development of Gasoline Direct Injection (GDI); a type of fuel injection technology in which fuel is being injected directly into the combustion chamber. By placing injector inside the combustion chamber, GDI technology provides more flexible injection-timing on the entire engine-operating conditions [9]. Injection timing can be set earlier during the intake stroke so that injection system can serve more homogeneous and rich mixture when the engine is operated under high load and speed conditions. The injection timing can also be set later during compression stroke so that the injection system can serve more stratified and lean mixtures when the engine is operated under low load and speed conditions.

The GDI's flexible injection-timing has been opening the opportunity for improvement on the conventional two-stroke gasoline engine design that was hampered by the characteristic of its scavenging process. By using GDI system, the fuel can be injected by the end of the scavenging process thus reducing the amount of fuel escapes from combustion chamber. Another advantage provided by GDI technology is the presence of charge cooling effect obtained through the fuel vaporization inside combustion chamber which will increase the engine's volumetric efficiency and reduce knocking [9]. The combined effect of the advantages of GDI technology had been proven to be able to deliver more economical fuel consumption and lower exhaust emission from four-stroke engine as well as two-stroke engine [1 - 7, 9].

Even with all the advantages that the GDI offers, its current application is limited only to the engine used in expensive cars or motorcycles. GDI technology demands better components than the available injection-components. Due to its location in combustion chamber, the GDI injector must be able to work properly at high temperature and pressure. The GDI injector must also be able to open and close in a very short time interval according to the command of the control system so that it can provide flexible injection-timing on the entire engine-operating conditions. Considering its effect on the improvement of fuel consumption and exhaust emission characteristic, the technology should be used more widely. In this work, several types of injectors had been investigated for their potential to be used as GDI injector applied on two-stroke engine. An experimental low pressure GDI system for two-stroke gasoline engine had been obtained and its fuel mass flow rate had been measured and compared to the carbureted version.

II. Experimental Setup

A. The Research Engine and the Components of Fuel Injection System

This research had been carried out on a water cooled, carbureted, and 148 cc two-stroke gasoline engine. The fuel injectors being investigated are: a stationary Diesel injector equipped with solenoid valve, a piezoelectric Diesel injector, and a four-stroke gasoline injector. All the three types of injector can be seen in Figure 1 mounted on the cylinder head of the two-stroke engine. The reason for selecting the Diesel injectors was based on the assumption that both injectors can withstand high temperature and pressure inside the combustion chamber. Furthermore, the stationary Diesel injector was chosen because it was designed to serve Diesel engine with capacity closer to the engine's capacity while the piezoelectric Diesel injector was chosen because it was equipped with a high speed piezoelectric actuator. The four-stroke gasoline injector was chosen based on the assumption that it had the closest fuel flow rate needed by the engine.

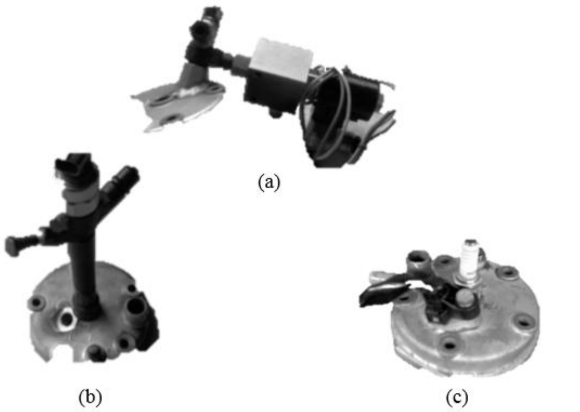

Figure 1. Three types of injector being used in this research: (a) 353 cc Diesel engine injector, (b) 2500 cc Diesel engine injector, and (c) 150 cc four-stroke gasoline engine injector

Due to the difference in operating pressure, hydraulic pumps were used to supply fuel to the stationary Diesel engine injector and piezoelectric Diesel engine injector while 150 cc four-stroke engine fuel injection pumps were used to control the four-stroke gasoline injector. The two types of fuel pump are presented in Figure 2. The injector control system uses Top Dead Center (TDC) position sensor, engine speed sensor, and throttle position sensor as data input for calculating the injection timing and injection duration. All data from the sensors was sent to microcontroller PIC16F87XA that was used as the injection control system.

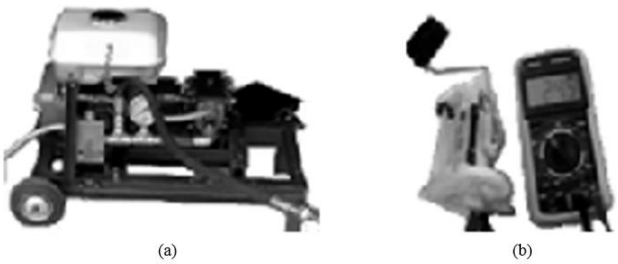

Figure 2. Two types of fuel pump being used; (a) hydraulic pump, (b) 150 cc four-stroke engine fuel injection pump

B. The Engine Fuel Consumption and Injectors Characteristics Measurement

The fuel consumption of the carbureted engine was measured by varying load and throttle opening to simulate the engine operating condition. The fuel consumption data were then used as fuel map data in fuel injection control program. The injector response time and fuel flow rate of the injectors were measured in order to evaluate their compatibility to the engine and injection system's designed-operating-condition. The injector response time data was obtained by placing accelerometer on the injector's body and then measure the time interval between injector opening/closing command and the injector actual opening/closing. The examples of the response time measurement is presented in Figure 3. Flow rate of the fuel from each type of injector was obtained by opening injectors and then measuring the time needed by injected fuel to fill certain amount of volume inside a burette.

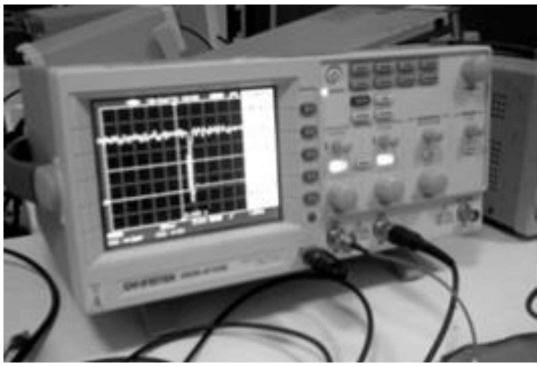

Figure 3. Example of oscilloscope reading of the injector open/close command and accelerometer signal

III. Results and Discussion

Maximum flow rate from each injector compared to flow rate required by engine at 100, 75, and 50 % throttle opening is presented on figure 4. All of injector flow rates are above the engine's required flow rate which means, from perspective of flow rate, all injectors can fulfil the requirement for the engine injector. Next thing to be consider is the ease of control when operating the injectors. Injector with highest maximum flow rate, in this case the piezoelectric Diesel engine injector, will be the most difficult to be controlled because the microcontroller and the rest of the electrical component in the injection control unit must be able to open and close in very short time at various engine operating conditions.

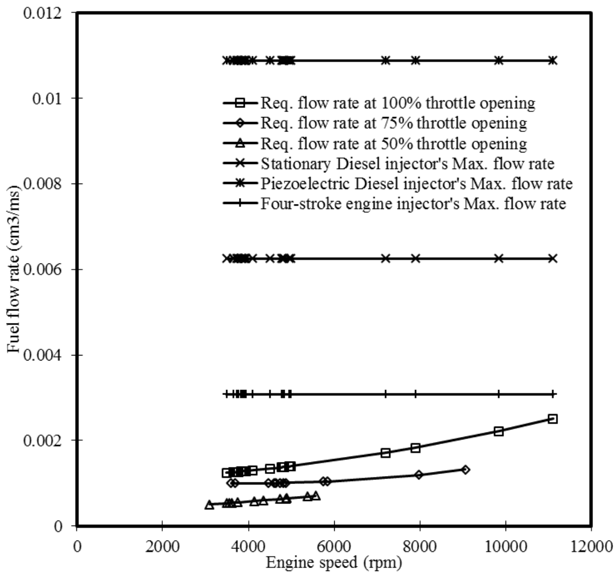

Figure 4. Maximum fuel flow rate of each injector compared to required fuel flow rate at 100, 75, and 50 % throttle opening

Figure 5 shows each injector's response time compared to one cycle duration of two-stroke engine and time available for two-stroke engine stratified charging at various engine speed. Ideally, injection for this two-stroke engine should be done in period between the closing of exhaust port and the start of ignition which is 70 Crank Angle Degrees (CAD) at under 4000 rpm and 64.5 CAD at 4000 rpm and above due to ignition advance at high engine speed. Moderately, injection may also be done in period between the start of compression stroke and the start of ignition when there is a little to none air flowing from scavenging ports to combustion chamber. The later injection strategy provide more available time for stratified charging between 105 CAD at under 4000 rpm and 99.5 CAD at 4000 rpm and above.

As can be seen in Figure 5, all but the stationary Diesel injector's response time are below the available time for two-stroke gasoline engine stratified charging. The measured total response times (open and close) were 33 ms for the stationary Diesel injector, 0.9 ms for the piezoelectric Diesel injector, and 1 ms for the four-stroke gasoline injector. With its response time, the stationary Diesel injector can barely work even at about 1500 rpm (idle condition) where time for one cycle duration is 40 millisecond. Due to that reason, the injector cannot be used as the engine's injector.

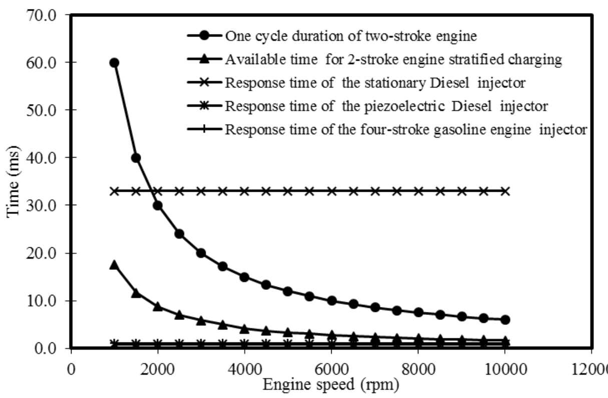

Figure 5. Injectors' response-time compare to one cycle duration of two-stroke engine and time available for two-stroke engine stratified charging at various engine speed

Next thing to be evaluated is the injection durations of the two remaining injectors when being operated according to the required fuel flow rate. Figure 6 shows simulated injection duration of the piezoelectric Diesel injector if operated according to the required fuel flow rate at 100, 75, and 50 % throttle opening. As can be seen in Figure 6, almost all of the injection duration values of this injector were shorter than the available time for two-stroke engine stratified charging (between 99.5 to 105 CAD). The injection duration is longer than the available time for stratified charging for engine speed beyond 7,000 rpm at 100 % throttle opening and beyond 9,000 rpm at 75 % throttle opening. Theoretically, the Start of Injection (SOI) can be advanced to positions before the Bottom Dead Center (BDC) on those conditions.

Even though the simulation data showed that the piezoelectric Diesel injector can be used reasonably well as the GDI injector for the engine, the implementation was proved to be too difficult to be done. The injector's piezoelectric actuator needs large amount of electrical current in the range of 10 to 15 amperes for its operation. Due to fuel supply requirement, the injector must also be switched on and off under 3 ms time interval for the entire engine operation range. Therefore, electrical component to be used as switch must be able to handle large electrical current yet at the same time must also be able to switch electrical current on and off in a very short time interval. The additional response times from sensor, electronic components, microcontroller, and the rest of injection control system were substantial enough that the actual total response time was much higher than total response time that had been calculated previously. As can be seen in Figure 4, there was big difference between maximum flow rate of the piezoelectric Diesel injector and required flow rate of the two-stroke engine. The difference implies that the slightest error in injection duration control will cause large error in the engine fuel supply. Combined effect of all those problems made stable engine operation using this type of injector was hard to be achieved and could not be accomplished in this experiment.

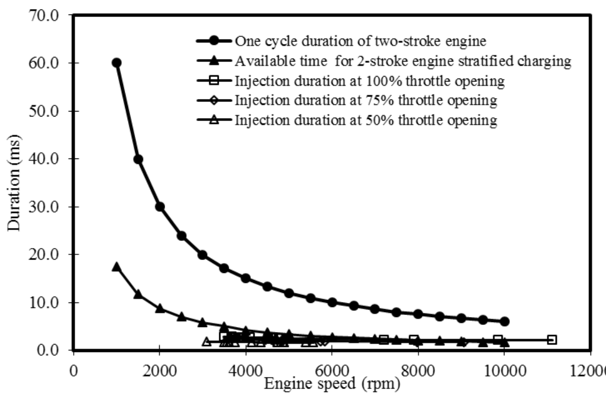

Figure 6. Simulated injection duration (including response time) of piezoelectric Diesel injector at 100, 75, and 50 % throttle opening compared to the available time for two-stroke engine stratified charging.

The gasoline injector was slower if compared to the previous piezoelectric Diesel injector, but on the other hand, as can be seen in Figure 4, the injector's fuel flow rate was the closest to the engine's required fuel flow rate. The simulated injection durations of this injector however, as shown in Figure 7, were longer than the available time for two-stroke engine stratified charging at all operating conditions. Starting on about 8000 rpm at 100 % throttle opening, the injection durations were even longer than one cycle duration of two-stroke engine. Stratified charging mode could no longer be achieved using this injector. For most of the time, the injector will be operated under homogeneous charging mode. Placing this injector in direct contact with combustion chamber was also not an option since the injector will not be able to withstand the temperature and pressure. It was decided then to change injector position to the place shown in Figure 8 instead.

Because of its new position, the injector will always be protected by piston from the high pressure and temperature during compression and power stroke but will still be able to inject fuel directly to combustion chamber in period between the start of the exhaust port opening to the end of the exhaust port closing (190 CAD). This fuel injection arrangement is called low-pressure GDI which similar implementation with different engine geometry had been described in [2, 3] and [8]. Controlling the four-stroke gasoline engine injector was easier if compared to the previous piezoelectric Diesel injector. The engine can run stably and responsively using fuel supply from this injection system.

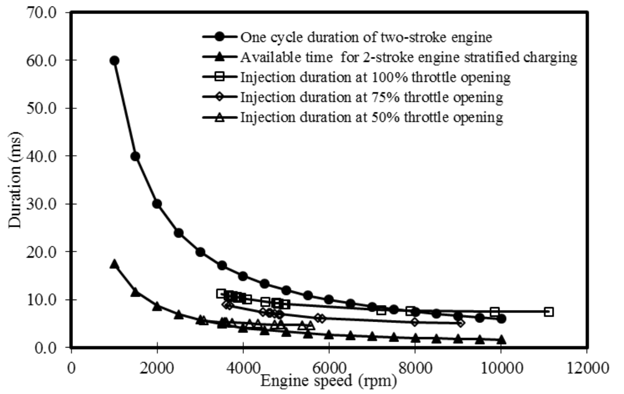

Figure 7. Simulated injection duration (including response time) of the gasoline injector at 100, 75, and 50 % throttle opening compared to the available time for two-stroke engine stratified charging and one cycle duration of two-stroke engine

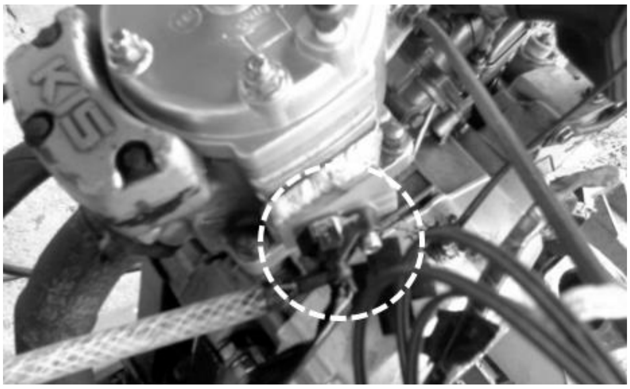

Figure 8. The position of the gasoline injector for low pressure GDI setup

Fuel mass flow rate of the low-pressure GDI system being produced was measured and calculated in order to evaluate the compatibility of the injector and the overall performance of the fuel injection system. Figure 9 shows the fuel mass flow rate comparison between carburetor and low-pressure GDI fuel supply system. Fuel supply in injection control program was designed to deliver 20 to 30 % less than the carburetor fuel rate. The measurement result showed that this intended fuel supply characteristics can only be obtained at low engine speed and small throttle opening. At condition other than that, low-pressure GDI's fuel mass flow rate is higher than the carburetor's.

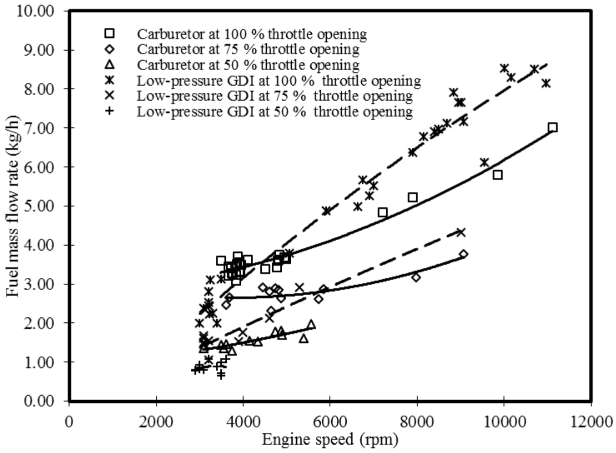

Figure 9. Fuel mass flow rate comparison between the time when the two-stroke engine used carburetor and the time when it used low-pressure GDI

IV. CONCLUSIONS

Investigation on a conventional Diesel injector, a piezoelectric Diesel injector, and a four-stroke gasoline injector to be used as GDI injector for two-stroke gasoline engine had been done. All of the injectors qualified if being evaluated with the capability to provide fuel flow rate according to the fuel supply requirement of the research engine. Only the piezoelectric Diesel injector and four-stroke gasoline injector qualified if being evaluated with the injectors' time response. Simulated injection duration data showed that the piezoelectric Diesel injector can serve almost satisfactorily at all engine operating points under stratified charging mode. Still, the control of the injector was very difficult and an excellent injector control unit was needed.

Simulated injection duration data of the four-stroke gasoline injector showed that it cannot be used with stratified charging mode. Fortunately, the homogeneous charging mode can still be done using this injector in low-pressure GDI configuration. A prototype of it had been produced and fuel mass flow rate measurement had also been done. The measurement showed smaller values of fuel mass flow rate at low engine speeds and small throttle openings if compared to condition when carburetor was used.

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