PFI System for Retrofitting Small 4-Stroke Gasoline Engines

Mohd Faisal Hushim, Ahmad Jais Alimin, Hazlina Selamat, and Mohd Taufiq Muslim

Abstract—**Fuel injection system is a promising technology that enhances positively the fuel economy, engine performances and emission reduction, as compared to the conventional carburetor system. Currently, motorcycles using carburetor system are widely used as a mean of transportation especially in urban areas. This conventional fuelling system produces more harmful emissions and consumes more fuel compared to the fuel injection system. It is therefore desirable to have a fuel injection system that can easily be retrofitted to the current on-road motorcycles. This paper presents a review and comparative study using 1-D simulation software - GT-Power, on electronic fuel injection (EFI) system between port-fuel injection (PFI) and direct injection (GDI) system for retrofitment purpose of small 125cc 4-stroke gasoline engine. From this study, PFI system has been selected based on its high brake power, brake torque, and brake mean effective pressure with low brake specific fuel consumption.**

Index Terms—**Fuel injection system, retrofitment, small gasoline engine.**

I. Introduction

Small gasoline engine refers to an internal combustion engine (ICE) with low size of combustion chamber – usually called as cubic centimetre (cc) ranging between 50cc to 150cc [1], and motorcycles are within this group. For many countries around the world, motorcycles using carburetor system are still the main option as a medium of transport for many people due to its mobility, convenience, economy and door-to-door functions. One advantage of motorcycles is that their high power to weight ratio that gives them good fuel economy.

From 26 million motorcycles registered in year 2001, 70% are from Asian countries while 8% accounts for Europe [2]. Based on statistic, in Malaysia, there are more than seven million motorcycles registered in year 2005 and increases by 28% in year 2009 [3].

Moreover, skyrocketing fuel price has also forced many people to opt for a motorcycle as a mean of transport for work and leisure rather than driving a car, for the sole purpose of reducing fuel cost.

However, due to large number of motorcycles on the road, this type of transportation has seen to be a major contributor of air pollution especially in urban areas for years. Air pollution in this area causes most health effect to people due to dense traffic and reduced air exchange between blocks of buildings. Due to low air exchange rate, this causes a build-up of higher air pollutant concentration. This polluted environment will give specific damaging effects, whether direct or indirect, such as health hazards, smog, acid rain, global warming, and ozone depletion. Therefore, many researchers have put forth strategic efforts to understand these environmental issues and find effective and innovative solutions, as well as looking forward for the future.

II. Electronic Fuel Injection System

Electronic fuel injection (EFI) system is a fuelling system that allows for controlling and supplying correct amount of fuel to the combustion chamber. Due to its capabilities, the EFI system is widely used and is believed to be an effective method of delivering fuel and reduce emissions.

As a potential alternative to conventional carburettor system, EFI system is designed to inject high-pressure fuel by the controlled fuel injector in a quantity appropriate to the amount of air being introduced at the inlet track (just before the intake valve opens), or directly into the combustion chamber. EFI system offers many advantages over carburettor system such as increased fuel economy, better cold starting capabilities, lower outputs of exhaust emissions and lower engine operating temperatures.

An EFI system comprised several major parts: electronic control unit (ECU) that controls the amount of fuel to be injected, fuel pump that provides pressure gradient to supply fuel to the fuel injector, and fuel injector that inject fuel in response to the input from ECU.

The fuel-injection systems for conventional spark-ignition engines can be defined by its fuel-injection location such as direct in-cylinder injection (GDI) and port-fuel injection (PFI). While GDI and PFI have much in common, but apparently they differ in some important ways. Table I provide the differences between these two types of EFI system.

According to Shim, Choi & Kim, [4], GDI system offers great improvements in fuel economy, performance and emissions control. The introduction of this system have greatly improve fuel economy and reduce exhaust emission for 2-stroke engine by scavenging the combustion product using air and supply fuel by direct fuel-injection to the combustion chamber [5]. However, Drake & Haworth [6],

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have said that, GDI fuel-injection system is more complicated and requires much more sophisticated control over the fuel-injection, air-fuel mixing and combustion processes compared to PFI system. This is because, rather than premixing the air and fuel, the fuel is injected directly into the combustion chamber and aimed at the spark plug and need higher compression ratio than PFI system. Application of GDI system to 4-stroke engine also presents many specific challenges [7]. Due to the fuel injector location that placed directly to the combustion chamber, the higher temperature and the exposure to the combustion environment can increase the risk of forming fuel injector deposits that can affect the engine's performance [8].

TABLE I: DIFFERENCES BETWEEN GDI AND PFI SYSTEM

Parameter	GDI	PFI
Injection location	Direct in-cylinder	Intake manifold
Type of mixture	Stratified-charge	Homogeneous-charge
Injector pressure	High	Medium
Side effect to the engine	Fuel injector deposits	Wall fuel-film

III. GT-POWER SIMULATION

A comparative simulation study had been done on the performances between PFI and GDI system for small 4-stroke single cylinder 125cc engine. The detailed specifications of the test engine are summarized in Table II. The study was done using 1-dimensional simulation software dedicated for automotive engineering: GT-Power. The developed model for both GDI and PFI system are shown in the Fig. 1 and Fig. 2 respectively.

TABLE II: TEST ENGINE SPECIFICATIONS

Engine Parameters	Setting / Remarks
Engine model	4-stroke
No. of cylinder and No. of valves	1 cylinder / 2 valve
Stroke x Bore (mm x mm)	57.94 x 51.75
Displacement (cc)	125
Compression ratio	9.3:1
Connecting rod length (mm)	130
No. of transmission	4 gear
Ignition system	Spark ignition
Cooling system	Air-cooled system

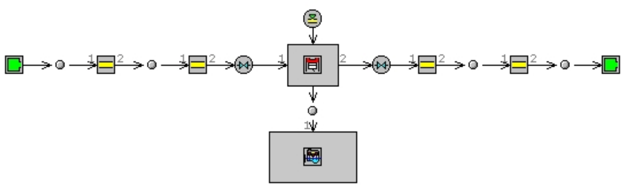

Fig. 1. The GT-Power model of GDI system.

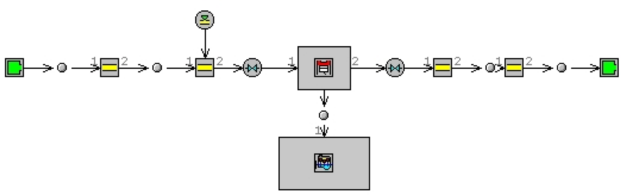

Fig. 2. The GT-Power model of PFI system.

Normal atmospheric environment has been set as boundary conditions for both inlet and outlet of the models. The developed models were simulated under steady-state situation, where the engine speed (rpm) starts from 1000 rpm until 10000 rpm with an increment of 1000 rpm.

Those two fuelling systems are compared for their performance outputs, which are Brake Power (BP) - Fig. 3, Brake Torque (BT) - Fig. 4, Brake Mean Effective Pressure (BMEP) - Fig. 5, and Brake Specific Fuel Consumption (BSFC) - Fig. 6. The comparison results are shown in the figures below.

From the figures, it can be seen that the PFI system is more powerful compared to GDI system which is its produces high BP, BT, and BMEP especially at 7000 rpm onwards as shown in the respective figures. At the same time, its consume less fuel with resulting low BSFC as shown in Fig. 6.

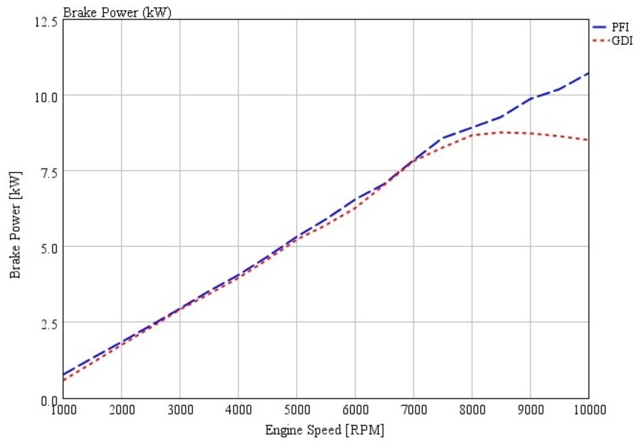

Fig. 3. Brake Power comparison between PFI and GDI system.

For BP, the PFI system has shown its significant power start from 7000 rpm onwards with over than 25% higher at 10000 rpm. For the GDI system, the highest power output was at 8500 rpm with its BP is 8.75 kW and its starts to decrease as the engine speed increase, while PFI system still providing power as the engine speed increase.

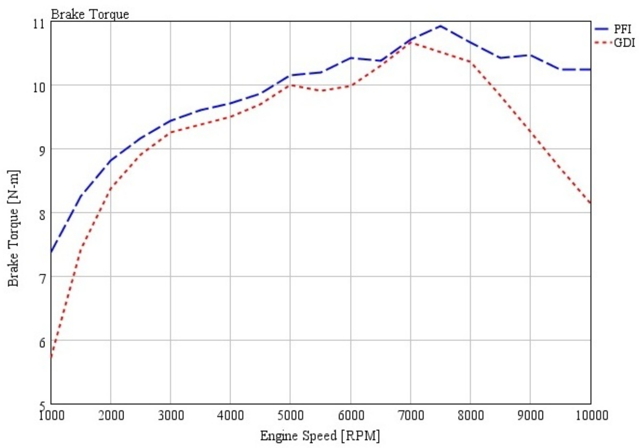

Fig. 4. Brake Torque comparison between PFI and GDI system.

Fig. 4 shows the variations of BT comparison between PFI and GDI system. From the figure, it can be seen that the BT for PFI system is higher all the time of engine speeds with the highest produced BT approaching 11 Nm at 7500 rpm. While the highest produced BT for GDI system is 10.66 Nm at 7000 rpm. PFI system has shown that it produced better BT compared to the GDI system with almost 29% and 26% higher at 1000 rpm and 10000 rpm respectively.

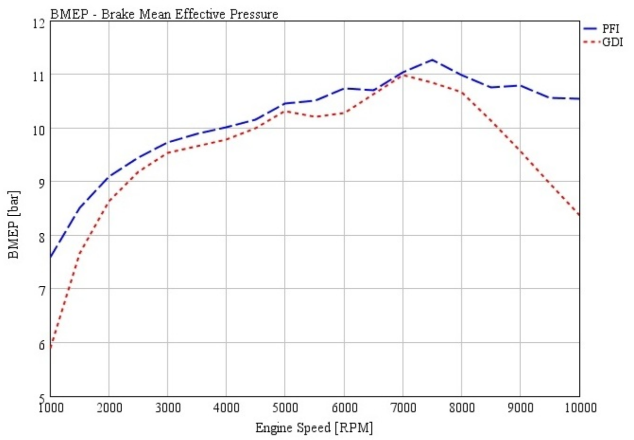

Fig. 5. Brake Mean Effective Pressure comparison between PFI and GDI system.

BMEP variations for PFI and GDI system are shown in Fig. 5. From the figure, it can be seen that the trend of BMEP curve follows BT curve. In order to evaluate the engine performance, BMEP is a criterion among other criteria that needs to be focused on. This indicates constant pressure acting on the piston during expansion stroke that produces power delivered by the engine. For an internal combustion engine, it is desirable to have high BMEP to produce high power per in-cylinder pressure. From the figure, it has been determined that the PFI system has the capability of producing high BMEP compared to the GDI system.

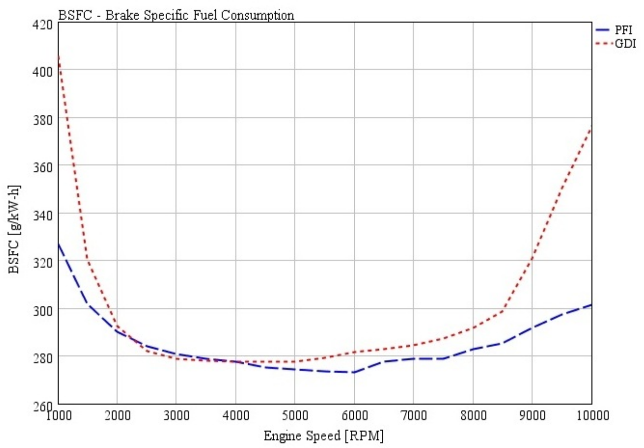

Fig. 6. Brake Specific Fuel Consumption comparison between PFI and GDI system.

Fig. 6 presents a comparison of BSFC between different fuelling system - PFI and GDI systems. It is common that, for all engines to have low values of BSFC. From the figure, obviously GDI system consumes more fuel almost at all engine speeds especially at low and high rpm. GDI system consumes over than 19% more fuel at low rpm – 1000 rpm and this value decreases as engine speed increases to 4000 rpm before its start to increase back as the engine speed increase and its end-up with almost 20% more at 10000 rpm.

IV. Cost Consideration

Despite the engine performance, when considering the small gasoline engines relative to automobile engines however, one important key difference immediately becomes apparent, namely: cost. The incremental investment cost of a new technology (fuel injection retrofit kit) which will be tolerated by the small engine user must be much smaller than the automobile user. Therefore, a simple, reliable and low-cost on the commercial side EFI system is important.

For this reason, the PFI system has been selected in this study because of its advantages over GDI system. Additionally, GDI system is too complex and costly, even difficult to implement on a commercialized engine. PFI system promotes low capital investment rather than GDI because GDI system is more expensive than PFI system. Meanwhile, GDI system has been found to emit higher numbers of particulates than PFI system [9]. Moreover, GDI system equipped best for 2-stroke engine because of its potential to control direct loss of mixture during scavenging phase while PFI system best for 4-stroke engine [10-13]. The PFI system as a fuelling system for internal combustion engine is shown in Fig. 7 below.

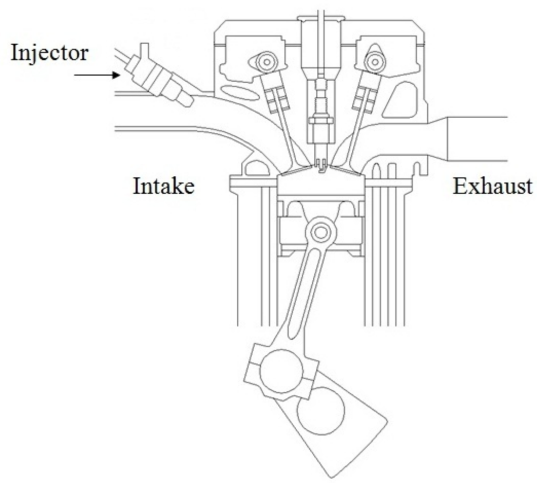

Fig. 7. PFI system for internal combustion engine.

In addition, the majority of the motorcycle engine components are conventional in design. In particular, the retrofit PFI kit uses conventional components of an engine except replacing carburettor and its intake manifold with retrofit PFI kit. It is therefore desirable to have a PFI system for small engines that offers all of the advantages of fuel injection over conventional carburetted engines, while having a low enough cost to make the system cost effective.

V. Conclusion

In this paper, a review and comparative study on electronic fuel injection system for retrofitment system for small 4-stroke gasoline engine has been discussed. PFI system has been selected because of its advantages based on:

- Low capital investment compared to GDI system;
- Best suited for 4-stroke engine;
- Mostly uses conventional components of an engine.
- Produces high BP, BT and BMEP and low BSFC.

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