Environmental Science and Technology Conference (ESTEC2009)
Kuala Terengganu Malaysia, December 7-8, 2009

Experimental Study On The Application Of Fuel Injection Retrofitment Kit For A Small Gasoline Fuelled Engine

A.J. Alimin[1]*, M.F. Ali[1], M.F. Mohd Ali[1], M.F. Mohideen Batcha[1], S. Md Seri[1], H. Selamat[2]
Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia
86400 Parit Raja, Batu Pahat, Johor
Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Johor, MALAYSIA

*Corresponding author:
Tel: + 607-4537711/8430 Fax: + 607-453 6080
E-mail: ajais@uthm.edu.my

Abstract – *In Malaysia, interest on motorcycles as the main choice of transport for works has increased recently, mainly due to the increasing fuel price. The majority of the motorcycles, especially those with cubic capacity less than 250cc, are equipped with the conventional carburettor system. Small gasoline fuelled engines operating using carburettor system, however, suffers from low operating efficiency, apart from producing hazardous emissions to the environment. In light of this situation, the current project will attempt to develop a retrofit fuel injection kit to address such challenges of meeting power requirement as a small cubic capacity prime mover and also in complying with the emissions regulations currently put in place. The experimental works on the proposed fuel injection retrofit kit is initiated by preparing a dedicated engine test rig equipped with the necessary instrumentation, which will allow analysis on the engine operating performance. Among the parameters to be investigated are engine torque, brake power, specific fuel consumption and engine thermal efficiency. Throughout the work, other key operating parameters that will also be monitored are the emissions levels of the exhaust gas and operating consistency and durability. It is expected that at the end of this research, the developed prototype will be able to work effectively in providing efficient fuel supply to power the small gasoline fuelled engine.*

Keywords – Durability, emissions control, fuel consumption, fuel retrofit kit, small gasoline engines.

1. INTRODUCTION

In many countries around the world, motorcycles using carburettor system are still the main option as a medium of transport for many people. From 26 million motorcycle registered in year 2001, 70% are from for Asian countries while 8% accounts for Europe [1]. Rising 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. In Malaysia, small engines are widely used in underbone motorcycle, mopeds and scooters. Since the first underbone motorcycle was borne in 1958 until now, not much technological advancement has been made to replace the carburettor system. Even though Malaysia has not yet implement any emission regulation for motorcycle and scooters, other developed countries already set their focus on reducing emissions from small gasoline fuelled engines.

2. CARBURETION SYSTEM

Carburettors have been used to supply a fuel and air mixture to both 4-stroke and 2-stroke small internal combustion engines. For small 2-stroke engines applications, carburettors with both a diaphragm fuel delivery pump and a diaphragm fuel metering system are utilised. In its typical operation, for 2-stroke engine, the carburetion involves entrainment of fuel in the intake air stream before intake air begins to enter the engine crankcase. The underside of the piston will compress the charged mixture and enters the cylinder when the piston uncovers the transfer ports. Continuous presence of combustion products from the previously completed combustion power stroke is forced out from the cylinder by this new air/fuel mixture. Unfortunately, the exhaust ports are also open at this time, allowing 30-40% of the fuel to be lost directly into the exhaust stream; at idle conditions the losses can be as high as 70% [2]. The high carbon monoxide emissions result from the unstable combustion inherent to carburetted two stroke engines. This instability requires that the engine be operated with rich air/fuel ratios to maintain acceptable combustion stability. This leads to incomplete combustion and high carbon monoxide levels. Finally, the high particulate emissions result from the unstable combustion, excessive lubrication (typical in small two stroke engines), and a lubrication system, which allows lubricating oil to be dissolved in the fuel. An illustration of this process is as Figure 1.

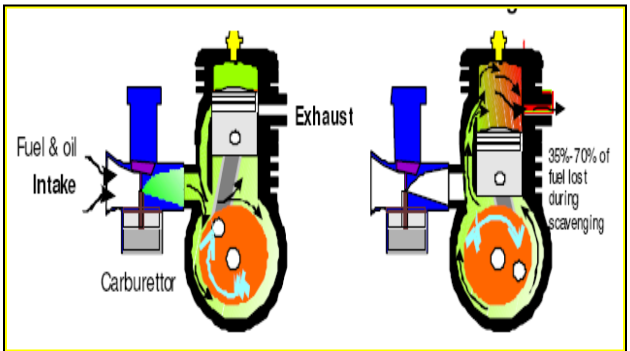

Fig. 1. Conventional 2-stroke engine, carburettor-based system; reproduced from [2].

3. FUEL INJECTION SYSTEM

A fuel injection system for a two-stroke small engine which injects a rich fuel and air mixture directly into the cylinder of the engine. The fuel injection system has a charge forming device which supplies a rich fuel and air mixture to a tuned injector tube connected adjacent one end through a port or valve to the engine cylinder and adjacent the other end to the engine crankcase. The charge forming device has an injector air inlet and fuel mixing passage to which, under engine wide open throttle operating conditions, at least a majority of the fuel is supplied by a high speed fuel circuit and preferably a minor portion of the fuel is also supplied by an idle fuel circuit. Preferably under engine idle conditions the idle circuit also supplies essentially all of the fuel to the engine.

Due to the relatively low selling price of two-stroke small engines and particularly two-stroke engines for handheld power tools, it is not economically feasible to utilize electronic fuel injection systems such as those typically used for automotive vehicle applications. While various lower cost mechanical fuel injection systems have been proposed for two-stroke small engines, some have either failed to meet the California and proposed emission standards or are economically and/or technically unfeasible for commercial manufacture and sale for two-stroke small engine applications such as handheld power tools [3]. Fuel injection system has proven to be an effective and durable strategy for controlling emissions and reducing fuel consumption from gasoline-fuelled engines.

There are two types of fuel injection system [4]:

i. <u>Direct Injection</u>

Fuel is injected directly into the main combustion chamber. The engines would have either one main combustion chamber or a divided combustion chamber made up of a primary and secondary chamber.

ii. <u>Indirect Injection</u>

Fuel is injected into the secondary chamber of engine with a divided combustion.

The fuel injection arrangement can either be based on the throttle body injection (TBI) or multi-port injection (MPI). A TBI system uses the same intake manifold as a carburetted engine, where the TBI replaces the carburettor. By injecting the fuel into the intake air stream, the fuel is better atomized than if it were drawn through with a venturi. TBI has the drawback of potentially large cylinder-to-cylinder variations. Like a carburettor, TBI injects the fuel into the intake air at a single location upstream of all the cylinders and this long and different travelling routes cause discrepancies in the amount of fuel that reaches each cylinder. Manufacturers account for this variation in their design and may make compromises such as injecting extra fuel to ensure that the cylinder with the leanest mixture will not misfire. These will eventually compromises combustion and fuel consumption [5].

MPI allocates a fuel injector at each of the intake port. A quantity of fuel is injected each time the intake valve opens for each cylinder. This allows manufacturers to more precisely control the amount of fuel injected for each combustion event, as well as optimising the air-fuel ratio for combustion. Due to these advantages, MPI system has been widely used in automotive applications for over 15 years [4].

One of the approaches being used to improve injector performance is air-assisted fuel injection, which injects high-pressure air along with the fuel spray to produce greater atomization of the fuel droplets can be achieved. This technology aids the improvement on engine performance and reduction of emissions at low engine speeds. In addition, industry studies have shown that the short burst of additional fuel needed for responsive, smooth transient manoeuvres can be reduced significantly with air-assisted fuel injection due to a decrease in wall wetting in the intake manifold [6].

4. ISSUES: FUEL INJECTION ON SMALL ENGINES

However, in dealing with small gasoline-fuelled engines, the application of a fuel injection kit still poses several interesting challenges, among others:

i. The added cost for an FI system must not considerably increase the total vehicle cost [7]
ii. Gasoline vapour lock due to thermal influence caused by a higher ambient temperature around air-cooled engine [8]
iii. The fuel pump must have low power consumption and must be small enough to fit into the gasoline tank [9]
iv. Obtaining accurate load detection at small throttle opening [10, 11]
v. The FI system must be able to operate only by kick-start when the battery is completely discharged [12]
vi. Measuring engine control data such as intake air mass, acceleration, stroke distinction and atmospheric pressure measurement [11]

5. THE PROPOSED RETROFIT KIT

The proposed prototype for fuel retrofit will have similar components as conventional fuel injection system. The main parts are fuel supply system, fuel injector and electronic control unit (ECU). A schematic example of this fuel injection system is as Figure 2.

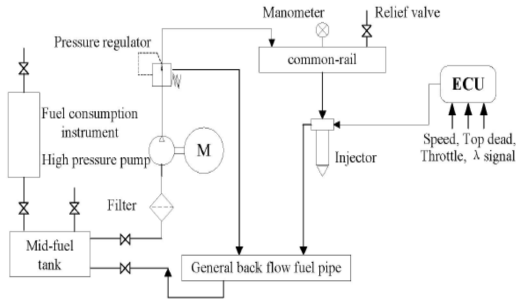

Fig. 2. Schematic of a fuel injection circuit; reproduced from [6].

Fuel Supply System

The fuel supply system provides a constant pressure resource for the injector. Basically, the fuel supply system is similar to the conventional design of gasoline direct injection (GDI) engine contained by high-pressure fuel pump, pressure regulator and common-rail. Previous study has developed fuel pump that supplies fuel to the rail at the pressure of 5-10 MPa. The pressure regulator maintains the pressure in the rail at the required level by regulating its fuel flow. The fuel rail stores fuel and prevents the pressure from fluctuation caused by nozzle opening and closing [13].

Electronic control unit (ECU)

The ECU controls the injection quantity and injection timing of the injector by special programs according to calculation and analysis of analogue and digital inputs of various sensors. During operation the ECU collects signals such as engine speed; TDC, throttle position and air flow. These signals will be processed and then used to control engine operation. At the same time, the ECU will also transmit several relative signals to PC for monitoring [13].

Fuel injector

Usually, inward opening swirl injector is the best choice for the engine with small displacement related to the optimum angle of fuel atomization and spray penetration. However, the research of (GDI) engines is still at initial stage and production of micro-injection swirl injector has not been a mature technique yet. The design and production processes for such swirl injector take a long time and the costs are quite high [14]. A typical schematic of a fuel injector that is designed for a common rail based fuel delivery system is as Figure 3.

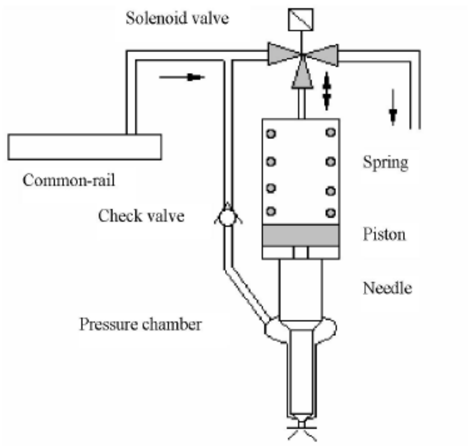

Fig. 3. Schematic of single injector for common-rail valve nozzle; reproduced from [14].

Table 1 below shows the proposed input and output, as well as the main controllers for the retrofit system.

Table 1. Input, controller and output for retrofit system

INPUT	ECU-CONTROLLER	OUTPUT
Throttle position	**Fuel injection control**	**Fuel injector**
Manifold absolute pressure	**Fuel pump control**	**Fuel pump relay**
Crank angle position	**Ignition control**	**Ignition coil**
Exhaust lambda value		

6. PROGRESS ON EXPERIMENTAL SETUP

The experimental works aim to assess the performance of a 4-stroke engine, operated using conventional carburettor and the developed fuel injection prototype kit. Assessment on the engine performance will be done using an asynchronous GUNT dynamometer as shown in Figure 4. Main parameters to be evaluated, at different engine speeds are: engine torque, brake power, volumetric fuel consumption, air/fuel ratio, thermal efficiency and brake mean effective pressure. Also shown in Figure 5 is the specialised metal connector, which has been fabricated to connect the dynamometer with the test engine.

Fig. 4. Engine test rig based on GUNT asynchronous dynamometer.

Fig. 5. Connector between the test engine and dynamometer.

Table 2 below shows the details on the dynamometer that will be used to assess the engine performance.

Table 2. Details on GUNT dynamometer

Parameter	**Description**
Power	**7.5 kW**
Torque	**50 Nm**
System	**Asynchronous dynamometer**
Fuel consumption	**Volumetric method**

In addition to that, description of the chosen test engine is laid out in Table 3.

Table 3. Details on the test engine

Items	**Description**
Number of cylinder	Single
System	4-stroke
Cooling type	Air-cooled
Bore × Stroke	52.4mm × 49.5mm
Compression ratio	8.8:1
Starter	Manual starting
Max. Power (kw/rpm)	5.3 [8000±500]
Max. Torque (Nm/rpm)	7.2 [6000±500]
Lubrication	Oil/splash
Fuelling	Carburetion

Further than that, instrumentation work is still on going, which will enable monitoring and data logging of the main engine operating parameters.

7. SUMMARY

In this paper, the proposed setup and configuration for developing a prototype of retrofit fuel injection kit has been described. The status of the current experimental setup and development has also been highlighted. Prior to those, issues involving installation of fuel injection kit has also been laid out.

ACKNOWLEDGEMENT

The authors would like to thank MOSTI for the financial aid through Sciencefund Grant Vot S017 and UTHM for the technical supports for conducting this research.

REFERENCES

[1] Hayakawa, K. Yamazaki, S. Takenaka, S. Oshiba, H. Yang, K. C. and Worth, D. 2004. *125cc Small Engine Fuel Injection System with Low Emissions Solution.* SAE Technical Paper No. 2004-32-0094.

[2] Dr. Bryan Willson Nathan Lorenz, Tim Bauer. 2002. Development of a Direct Injection Retrofit Kit for Reducing Emissions from 2-Stroke Cycle Engines in Asia.

[3] Fraidl G K. Gasoline. 1996. *Direct Injection: Actual Trends and Future Strategies for*

Injection and Combustion System. SAE Technical Paper No. 960465.

[4] Willard W. Pulkrabek. 2004. *Engineering Fundamentals of the Internal Combustion Engine*. 2nd ed., Upper Saddle River, NJ: Pearson Education.

[5] Peters, Eric. 1997. *Fuel injection*, Consumers Research Magazine, 00952222, Sep97, Vol. 80, Issue 9.

[6] Zhao F, Lai M C, and Harrington K L. Automotive. 1992. *Spark-Ignited Direct-Injection Gasoline Engines* [J]. Progress in Energy and Combustion Science 1999, 25: 437-562.

[7] Ujiie, T Saito, H. Ueda, M. Akamatsu, S. Hayashi, A. and Nakano, Y. 2005. *Development of Fuel Injector and Fuel Pump for a Fuel Injection System to Use in Small Motorcycles*. SAE Technical Paper, No. 2005-01-0047.

[8] Komuro, K. Yagisawa, K. Akamatsu, S. Hayashi, and Ueda,M. 2005. *Fuel Injection System of Air-Cooled Engines for Small Displacement Motorcycles*. SAE Technical Paper, No. 2005-32-0035.

[9] Karasawa, T., Hashimoto, S., and Ehara, R. 2005. *Development of Discharge Pump Type Fuel Injection System for Small Two-wheel Vehicle.* SAE Technical Paper, No. 2005-32-0022.

[10] Almkvist, G., Karlsson, T., Gren, S., Bengtsson, J, Andersson, C. and Oskarsson, P. 2001. *Fuel Injection System for a High Speed Single Cylinder SI Engine.* SAE Technical Paper, No. 2001-01-1863.

[11] Nakamura, M., Sawada, Y., and Hashimoto, S. 2003. *Fuel Injection System for Small Motorcycles*. SAE Technical Paper, No. 2003-32-0084.

[12] Tamaki, K., Kokubu, S., and Akamatsu, S. 2004. *Control Device of Electronically Controlled Fuel Injection System of Air-cooled Engines for Small Motorcycles*. SAE Technical Paper, No. 2004-01-0901.

[13] Jiang Jian and Gao Xiyan. 2004. *The Development of Direct Injection Spark Ignition Engine* [J]. Chinese Internal Combustion Engine Engineering, 25 (1): 54-57.

[14] Jiang Jian, Gao Xiyan, and Yao Chunde. 2009. *An Experimental Study on Fuel Injection System and Emission of a Small GDI Engine*.