AN OVERVIEW ON DURABILITY STUDY ON A RETROFIT FUEL INJECTION KIT DURING ON-ROAD TESTING

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ABSTRACT
Various researches have been done on the development of a retrofit fuel injection kit for small capacity engines such as lawn mowers and underbone motorcycles as a solution to the emission problems caused by these small gasoline engines. However, the implementation of these retrofit kits has so far been limited to be used in lab tests only. The system is too bulky to be used on road. Furthermore, the durability issue of the system on the road has not been stressed out so far. Thus, the challenge here is to conduct an on-road durability study of the retrofit fuel injection kit when it is fitted to a MOMOS 115cc motorcycle engine. For this purpose, the system configuration settings must be suited for the use on the MOMOS 115 cc motorcycle engine. This is done by implementing the ECU (electronic control unit) mapping of the configuration settings for the motorcycle application. The durability of the system will be evaluated quantitatively and qualitatively. Previous test was done on a 125 cc NAZA Flash motorcycle engine to evaluate the performance curve and fuel economy of the engine equipped with the retrofit fuel injection kit. The test was done using the Gunt CT110 test stand. The result showed that the performance of the engine when using the retrofit kit had improved compared to that when equipped with a carburetor. It also showed an improvement on the fuel economy. At the end of this research, it is expected that the durability study will provide indications that it is possible for the retrofit kit be used on the road with minimal problem.

Keywords: *durability, on-road testing, ECU mapping, retrofit kit.*

1. INTRODUCTION

Underbone motorcycles, also known as "cub" are one of the most popular mean of transportation among Malaysians. The reason for this is mainly because the costs for these small motorcycles are far cheaper and affordable than passenger cars. Besides that, they are very easy to operate. However, since the first one was produced in 1958, these underbone motorcycles have not changed. They still use carburetor to deliver fuel to the engine [1]. Carburettors had always been associated with emission problems, high fuel consumption, and hesitation during acceleration, and poor start-up [2]. It would the reason why fuel injection systems have replaced the troublesome carburetor in modern cars.

A lot of researches have been conducted on the development of a retrofit fuel injection kit for small capacity engines. Previous researches have tested and proven that retrofit approach is feasible. But, these tests are normally done one laboratory scale. Moreover, the current prototype is still too bulky to be used on the road. Thus, an on-road testing is required for the system to be fitted onto a motorcycle. Plus, the durability issues of the system have not been brought up yet. So, the aim of this project is to define the durability of the system when it is used on the road. So, this paper will review on the ideas towards the research goal.

Although there are a few aftermarket products that offer the retrofit fuel injection kit with similar applications, the author believes that there are still a lot to be done in studying the long term effect of these retrofit fuel injection kit. Moreover, these aftermarket products are still costly with all the sensors and equipments. The need to minimize the components used will be an added advantage in this research.

This paper intends to review on previous studies that have been made and extract ideas from literature study. Thus, implicate the ideas from literature to design and plan the experimental work frame.

2. AIR-FUEL RATIO

For an internal combustion engine to run effectively, fuel and air is needed to enable the combustion to occur, and hence transforms the heat into mechanical work. The correct amount of fuel and air mixture is very important for the engine to do it's job properly. Too much fuel will cause incomplete combustion, and hence emits harmful emission such as carbon monoxide [2]. Furthermore, if the engine consumes too much fuel, it would definitely point out that the engine cannot operate for a long period of time. This would not be desirable if it was an automotive or motorcycle engine.

However, if there is not enough fuel in the system, the engine will hesitate during acceleration, overheat, and knocking will occur due to overheating [2].

Air-fuel ratio is another way to express the mixture quality and how much fuel the engine consumes.

3. CARBURETTOR

The carburetor is a device that introduces fuel into the intake air. A simple carburetor is constructed of a small diameter fuel jet, located at a constricted passage called the venturi throat, and a float chamber having a float and a needle valve attached to the float [3]. This can be seen in Figure 1.

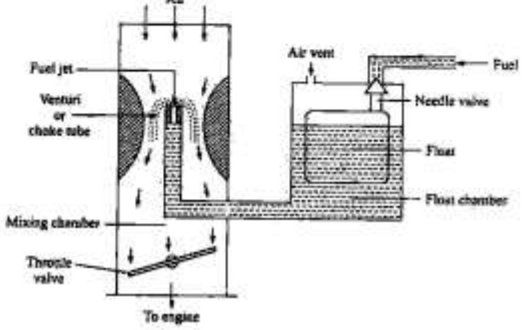

Figure 1. Simple Carburetor; reproduced from [3]

The needle float valve maintains the fuel level inside the float chamber, whereas the air vent maintains the pressure at the fuel surface so that it experiences atmospheric pressure. When the throttle is open, air rushes in due to the suction caused by the piston's downward motion in the cylinder. At the venturi throat, the air pressure drops below the atmospheric pressure. Since the fuel surface inside the float chamber experiences atmospheric pressure, the fuel is forced to exit the jet due to pressure difference created at the throat. This mixes the fuel with the intake air [2].

The restrictions in the venturi throat, jet orifice, throttle valves, and runner bend causes the loss of volumetric efficiency. Even during sudden accelerations, the engine hesitates and sometimes can stall due to insufficient fuel in the mixture. This proves to be dangerous for a car when pulling out a junction. The poorly distributed mixture delivered by the carburetor, where not all the fuel are vapourized, can cause incomplete combustion which in turns, upsets the quality of the exhaust gasses [4].

In carbureted two-stroke engines, the fuel entrainment takes place before the intake charge enters the crankcase. The charge is then compressed in the crankcase beneath the piston. During that time, the piston uncovers the intake port letting in the fresh charge and forcing out the exhaust charge. Because both intake and exhaust occur at the same time, 30%-40% of fuel in the intake charge is expelled along with the exhaust. The percentage can reach as high as 70% at idling [5].

The problems highlighted however, opened some research opportunities related to the improvements and developments of the carburetor. One of them was the invention of vapourizing carburetor in 1975 which was lead by Tucker. The development of the vapourizing carburettor was then continued where; the use of ethanol-gasoline blend was applied [4]. Figure 2 shows the schematic diagram of the vapourizing carburettor. The result obtained was compared to the conventional carburettor, shows that the advantage is favoured by the vapourizing carburettor.

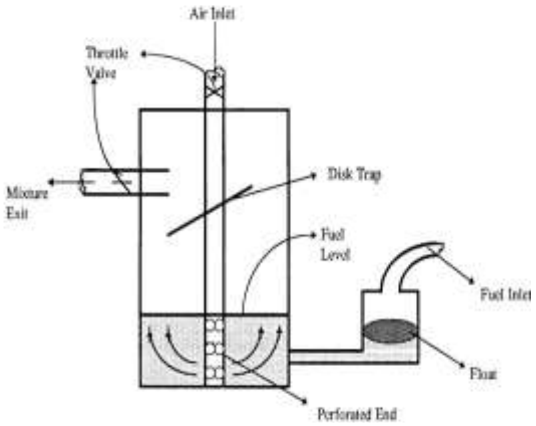

Figure 2. Vapourizing Carburetor; reproduced from [4]

The research on using ethanol-gasoline blend as fuel in a spark-ignition engine equipped with a modified carburettor [6], had also been done as another respond to the problems associated with carburettor that have been previously mentioned by [6]. The author in [6], pointed out, that engine consumes more fuel when using the fuel blend compared to that when the engine is running on pure gasoline. Moreover, the torque produced by the engine is lower when using the blended fuel than when it is running on pure gasoline.

The researches done by [4] and [6], are some of the response in tackling the problems with carburetor. However, the data were not compared to with the fuel injection technology. This does not mean their researches are not necessary. The results reported, have justified the need to develop a solution or alternative for carburetor.

4. FUEL INJECTION

Modern engines have turned to fuel injection system to replace the troublesome carburetor. Basically, both share the same function; to deliver fuel for the engine. The only difference is that the injector delivers an almost correct amount of fuel at the precise timing. This means the engine can run efficiently, with fewer pollutants emitted.

Fuel injectors used to be mechanically controlled. But nowadays, the system was replaced by a more sophisticated electronic fuel injection system, or EFI. The reason is that, mechanical injector increases engine load due to several mechanical losses just to control the system [3].

Basically, there are two classes of fuel injection system that are currently in use. Both are electronic controlled. They are the direct injection system for gasoline (GDI), and the indirect injection system [1].

4.1 Gasoline Direct Injection

In this particular system, the gasoline direct injection (for spark ignition engine) injects the fuel directly into the combustion chamber, similar to that of a diesel engine. In this type of system, the cylinder head consist of two ports (other than valve ports); one for the injector, and the other for the spark plug. These types of injection system are very costly because of the modifications and design constraints [1, 7]. This includes the introduction of a high-pressure pump driven off the crankshaft, and issues with cylinder wall wetting which can have effect on the durability of the engine [7]. The system alone is very complex. This is why modern engines still prefer indirect injection over direct injection.

4.2 Indirect Injection

In these type of injection system, the injector is located upstream of the intake port. It could either be situated at the throttle body (throttle body injection) or at the intake runner (port injection). The throttle body injection has its drawback because it is very similar to the carburetor. For multi-cylinder engines, the problem will always be non-uniform vapour distribution of intake charge in each cylinder [3]. Furthermore, intake back-flow will cause the access fuel to be wasted, because the fuel is injected before the throttle valve. Whereas, port injection have better chance of uniform distribution and fuel economy [3]. The fuel is injected at the intake port towards the intake valve. This is why most of the vehicles nowadays use the port injection system. Furthermore it only requires minimum modifications to be able to use the system.

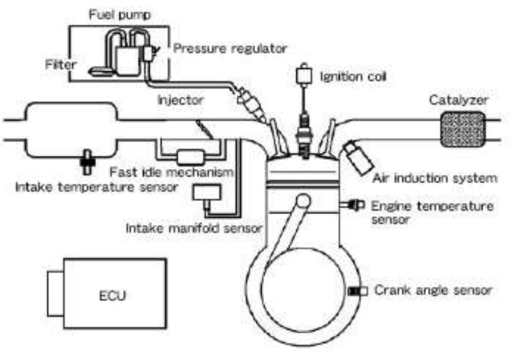

Figure 3. Overview of the port injection system; reproduced from [11]

5. LITERATURE REMARKS

The research conducted by [4] and [6] implemented on blending alcohol with gasoline as a low cost solution to the problems imposed by the carburetor.

The author believes that these research done by [4] and [6] justifies the need to improve fueling system in an internal combustion engine.

Reference [1] had proposed the retrofit fuel injection kit for use on small capacity engines. This is an advantage to the author as reference [1] gave some enlightenment on how the system should be operated, along with the experimental setup.
Previous study had proved that retrofitting the fuel injection system on a NAZA Flash engine with the capacity of 125 cm^3 is possible whereby; there have been improvement in reducing the fuel economy [8]. However, the output torque and power did not show any improvements.

Meanwhile, [7] had ruled out the potential advantage of gasoline direct injection for a small four-stroke engine. It is found that, there are still many challenges in developing the direct injection system for small capacity engine. This is why this research focused on port fuel injection. Although [7] came up with improvement of fuel economy, there is still an issue with the installation cost. Not to mention the additional hole that needed to be drilled in the cylinder head.

Despite the detailed work done by [7], the durability of the system had not been evaluated.

The durability implications of fuel a modulated fuel injector was done by [9]. However, [9] focused on the hydrogen-fuelled engines. Although the focus was placed on hydrogen-fuelled engines, the author believes that [9] have highlighted some important information, especially on how to evaluate the durability of fuel injection system. Only difference is the use of fuel. Furthermore, this research focuses more on small capacity engines.

The study from reference [10] showed the relationship between the throttle angle, engine rpm, with injection pulse width (period of injection) via a 3D mapping. This will later be useful in calibrating the ECU data with other parameters involved. Hence, the one of the job scope can be fulfilled which is, ECU mapping and configuration.

6. PROPOSED STRATEGY

The proposed retrofit fuel injection is constructed using the same components as that in the current available system.

Specifically, it will be very identical to the one proposed by [1] and [11]. Though, some of the sensors are eliminated so that the kit would not be too bulky [1]. Although there is bolt-on type fuel injection kit available in the market, the system still has its' limitation which is, the kit did not have any input means of detecting the intake stroke. So, the addition of the intake valve position signal as an input for injection timing is needed to be able to set the best moment when the injector should start spraying.

6.1 Injection Timing

This can be done either by placing a limit switch (neutrally closed) at the cap on the cylinder head as shown in the figure. However, the use of mechanical limit switches will have durability issues. This is because these switches have never been used on such conditions before (i.e: high stress). Therefore, before using that concept, it needs to be tested first.

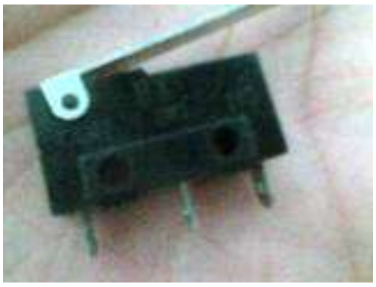

Figure 4. Limit switch.

Other than the use of a limit switch, it is also possible to use some kind of stationary electromagnetic pickup and a moving coil attached to the valve stem or rocker arm. This concept is similar to that on an electric guitar [12] where, Faraday's law of induction is applied. Again, the high temperature might be an issue for the pickup. It might not work effectively under such conditions. This must also be tested via small scale experiment.

6.2 ECU Mapping

In general, the purpose for ECU mapping is to create a model of the engine behaviour in relation to the manipulative parameters, and optimize these parameters to meet desired restrictions [13]. In this case, the purpose of ECU mapping is to gather data from various sensors to relate with the amount of fuel injected or to be precise, the pulse width. The data obtained are then used for configuration settings of the system. To obtain such data, the ECU will need to be calibrated first. This can be done experimentally. This experiment will be conducted on a test stand using GUNT dynamometer. The experiment will be identical to [1]. However, the rpm ranges in [1] were only focused around 1000 to 2000 rpm. So, this study will increase the rpm ranges.

All the data gathered from the experiment will be collected and stored. Then, the values from the data will be used in the ECU for configuration setting.

Table 1. Specifications of the GUNT dynamometer; reproduced from [1]

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

6.3 On-Road Testing

The on-road testing will be conducted and mimic the real driving conditions, whether it is an urban driving condition or highway driving condition [14], this study will do both. The MOMOS Tigris 115 s motorcycle will be used as the test motorcycle. The table shows the technical specification of the test motorcycle issued by Mofaz Sdn Bhd.

Table 2. Engine specifications of thetest motorcycle.

Items	Description
Max. Power (kW/rpm)	5.07 kW/9500 rpm
Max. Torque (Nm/rpm)	7.87 Nm/7500 rpm
Displacement volume	114.68cm^3
Camshaft configuration	Single overhead camshaft
Cooling system	Oil cooled
Idling speed (rpm)	850-900 rpm
Ignition	Magneto CDI

Bore x Stroke	52 x 54
Compression ratio	8.9:1

The total distance of the on-road test will cover in between 100 km to 500 km. Various speed ranges will be applied to mimic typical driving conditions on the road.

6.4 Durability Study

The durability study will be conducted before, during, and after the on-road test. The data during and after the on-road test will be compared with the data before the on-road test. This is so that the effect after such distance can be evaluated and assessed. Thus, the behavior of the engine performance, fuel consumption and other parameter can be identified.

7. EXPERIMENTAL FRAMEWORK

The aim of the experimental work is to define the durability of the retrofit fuel injection kit when it is used for on-road application. In order to achieve that, the experimental works consisted of three phases where, each phases have its own milestone to be completed. The process is shown in figure 5.

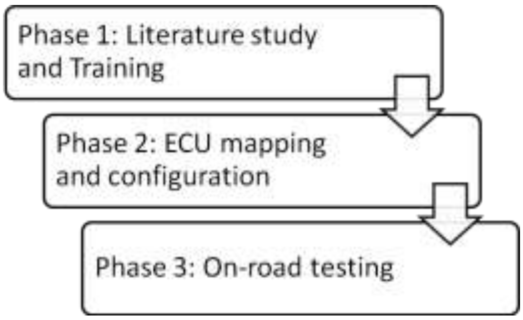

Figure 5. General process of this research.

The figure 5, shows the flow of the different phase of this project in which, it will start with gathering knowledge and various information via literature works or brief training. The brief training classes was conducted by previous experts on the existing prototype. From the brief training, the problems and limitations of previous studies were issued. Hence, ideas can be generated for completing one of the milestones. Other than that, the tasks required to complete this phase will be; to develop the ECU programming. Lastly, before moving on to the next phase it would be important to practice the upcoming experiments via pilot tests. This includes the on-road test for motorcycle. However, the literature work is still an on-going process until the end of this project.

The second phase of this project is the ECU mapping and configuration settings adjustments. To complete this phase, it is required to carry out an experiment using the test stand as explained in part 6.2. The experimental data which, in this case would be pulse width, crank angle or rpm, shutter valve opening, and injection timing will then be stored. After that, the engine behavior can be visualized via a 3D map. The data from the mapping process can then be stored in the ECU memory for configuration settings. Simply put, the value from the 3D map can be used as a look-up table [10].

Finally will be the road test. Again, there are several tasks that needed to be done in order to achieve the aim of this project. At this phase, the task will by installing the retrofit kit onto the test motorcycle that has been mentioned in table 2. Then, just like in the second phase, the ECU needs to be reconfigured and remapped to match the specification of the motorcycle. Therefore, the motorcycle must undergo an initial chassis dynamometer run before the road testing. This is again to obtain the data to be stored in the ECU. The following task will be to test the retrofit kit on the road, and lastly another run on the chassis dynamometer to evaluate the effect on the performance after a long run.

7.1 Progress

The main goal of this project is to define the on-road durability of the retrofit fuel injection kit. As mentioned before, each stage or phases have several milestones to be executed in order to achieve the main goal. Currently, the first phase is still on-going and almost complete. The only task left are to develop the ECU program, and complete the pilot testing. Though, the

ECU required some modifications, plus the problems mentioned in part 6.
The basic parameters that will be evaluated in this study are: torque, power, fuel consumption, air-fuel ratio, engine speed, crank angle (injection timing), pulse width, shutter valve opening (throttle position), and response of the engine.

8. CONCLUSION

In this paper, the experimental works have been suggested. Previous research had also been reviewed and studied to help complete this research project. Despite the problems and issues that had been drawn, the author believes that by adhering to the plans laid out, these problems can be tackled.

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REFERENCES

[1] Alimin, A. J., Ali, M. F., Mohd Ali, M. F., Mohideen Batcha, M. F., Md. Seri, S., & Selamat, H. (2009). Experimental Study On The Application Of Fuel Injection Retrofitment Kit For A Small Gasoline Fuelled Engine. *Environmental Science and Technology Conference (ESTEC2009).* Kuala Terengganu: UTHM.

[2] Pulkrabek, W. W. (2004). *Engineering Fundamentals of the Internal Combustion Engine 2nd Edition.* Upper Saddle River: Pearson Education.

[3] Gupta, H. N. (2006). In H. N. Gupta, *Fundamentals of Internal Combustion Engine.* New Delhi: Prentice Hall of India.

[4] Abu Qudais, M., Asfar, K. R., & Al-Azzam, R. (2001). Engine performance using vapourizing carburetor. *Energy Conversion Management 42* .

[5] Willson, B., Bauer, T., & Lorenz, N. (2005). Design of a Direct Injection Retrofit Kit for Small Two-Stroke Engines. *Small Engine Technology Conference and Exposition.* Japan: SAE International.

[6] Yüksel, F., & Yüksel, B. (2004). The use of ethanol-gasoline blend as a fuel in an SI engine. *Renewable Energy 29*

[7] Cathcart, G., Rodney, H., & Ahern, S. (2004). The Potential of Gasoline Direct Injection for Small Displacement 4-Stroke Motorcycle Applications. *Small Engine Technology Conference and Exposition* .

[8] Mohamad Zen, A. A. (2010). *Performance Comparison Between Fuel Injection and Carburetor System.* Parit Raja: UTHM.

[9] Kabat, D. M., & Heffel, J. W. (2002). Durability implications of neat hydrogen under sonic flow conditions on pulse-width modulated injectors. *International Journal of Hydrogen Energy* .

[10] Gonzalez, E. G., Florez, J. A., & Arab, S. (2008). Development of the management strategies of the ECU for an internal combustion engine Computer simulation. *Mechanical System and Signal Processing* .

[11] Nakamura, T., Hasegawa, T., Suzuki, M., Nakamura, M., & Sawada, Y. (2003). *Fuel Injection System for Smaller Motorcycles.* Japan: Yamaha Motor Technical Review.

[12] Lemarquand, G., & Lemarquand, V. (2007). Calculation Method of Permanent-Magnet Pickups for Electric Guitars. *IEEE Transactions on Magnetics , 43* (9).

[13] Gokce, M., Kozan, R., & Tamyaz, I. (2009). An Experimental Approach for Engine Mapping. *Modern Applied Science , 3* (3).

[14] Walkowicz, K., Na, K., Robertson, W., Sahay, K., Bogdanoff, M., Weaver, C., et al. (2009). On-Road and In-Laboratory Testing to Demonstrate Effects of ULSD, B20,. *SAE Powertrain, Fuels and Lubricant Meeting.* San Antonio: SAE Technical Paper.