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Research Paper

Design and Experiment of a Prototype Electronic Control Unit Direct Injection Fuel System Arduino-Based for 2-stroke Spark Ignition Engine

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Abstract

The development of technology on the 2-stroke direct-injection spark-ignition engine is expected to be a solution to optimize engine performance and reduce exhaust pollution. The fuel injection system in the operation of the spark-ignition engine is controlled by the Electronic Control Unit (ECU), so this study aims to design and experiment with a prototype of an Arduino-based direct injection fuel injection electronic control unit for 2-stroke spark-ignition engines. This research method begins with the design of an electronic control unit prototype that is selected for easy setup and low cost. Then, experiments were conducted on variations in injection timing and injection duration, which are the two main parameters of the fuel system to determine their effect on engine performance. This data is then used as a basis for setting the amount of fuel injected. The results show that there is an optimal performance under certain conditions from setting the injection timing and injection duration which is easily applied to the open-source code setting of this electronic control unit.

Keywords: ECU; 2-stroke; Spark ignition; Direct injection; Arduino

1. Introduction

The 2-stroke spark ignition engine completes its cycle in one crankshaft revolution [1]. Meanwhile, the drawback of this engine is that it is a waste of fuel because, during the scavenging process there is the fuel that comes out directly through the exhaust port, this is the cause of this engine producing high HC pollution in the exhaust gas [2]. To overcome this problem is to modify the fuel system from a 2-stroke spark-ignition engine to a direct injection fuel system so that, the wasted fuel along with the exhaust gas during the scavenging process can be avoided [3]. In addition, using a direct injection fuel system will improve engine performance [4], [5]. This is because direct injection technology allows homogeneous combustion with the right mixture so that it reduces exhaust emissions, improves fuel efficiency, and increases engine power [6], [7].

Research and application of direct injection fuel system technology are currently generally carried out in compression ignition engines [8]–[12]. The studies for direct injection fuel system spark-ignition engine technology are still focused on 4-stroke engines [13]–[16]. Simulation study of the 2-stroke direct injection spark ignition engine promises to improve fuel energy conversion [17] and reduce exhaust emissions [18], [19]. Furthermore, experiments on 2-stroke direct injection spark ignition engines using gas fuel have also been carried out [20], [21]. However, these studies have drawbacks that the gas fuels used are difficult to obtain at gas stations, unlike liquid fuels. Therefore, there needs to be research that uses liquid fuel that is easy to obtain is liquid fuel. Initial studies limited to being able to operate the engine using a pneumatically compressed liquid fuel to determine the effect of variations in

Nomenclatures	
AC	Alternating current
BMEP	Brake mean effective pressure
BDC	Bottom dead center
aBDC	After bottom dead center
bBDC	Before bottom dead center
CDI	Capacitor discharge ignition
ECU	Electronic control unit
HC	Hydrocarbon
HP	Horse power
ms	Milliseconds
rpm	Revolutions per minute
RON	Research octane number
TDC	Top dead center
TPS	Throttle position sensor

fuel pressure and the effect of injection timing have proved to be a successful concept [22], [23].

The fuel injection system in the operation of the spark-ignition engine is controlled by the Electronic Control Unit (ECU). The existing ECU from the factory is tuned according to the specific engine requirements, so modifying the system requires remapping and recalibration through a difficult procedure [24], [25], therefore it is necessary to develop an open source-based ECU that can be easily reprogrammed. Study on design and development of a prototype Arduino-based low-cost open-source electronic control unit for electric utility vehicles, experimental results have proven to be fully functional and robust [26],[27]. The design and experiment of anti-collision control for Arduino-based smart vehicle systems further obtained the results that the Arduino processing unit can be modified by adding more sophisticated designs including speed control, ignition pollution, etc. [28]. Further development of modern open-source technology for electronic stability control units (ESC ECU) [29] and ECU security systems with real-time processors on the Arduino platform can be implemented successfully [30]. The application of hardware to control the operation of engine functions, by the Arduino ATMEGA Microcontroller-based ECU for the compression ignition engine fuel injection system, can achieve several variations of fuel flow with a fixed fuel injection time at a constant airflow rate condition [31]. However, design studies and experiments of an open-source low-cost Arduino-based ECU for direct injection fuel systems in 2-stroke spark ignition engines have not yet been developed.

This study aims to design and experiment with a prototype electronic control unit direct injection fuel system Arduino-based for 2-stroke Spark Ignition engine. This research will concentrate on the effect of injection timing, and injection duration on the performance of the 2-stroke direct injection spark ignition engine, to obtain the fuel injection mapping characteristics that produce an optimal performance as the basis for the instruction code in programming this ECU prototype.

2. Method

2.1. *Materials*

The 2-stroke spark ignition engine used in this study is a 1997 Yamaha F1ZR motorcycle engine with a capacity of 110,4 cc engine, the engine specifications are shown in Table 1.

Table 1. Engine specifications of 1997 Yamaha F1ZR motorcycle [32].

Type	:	2-stroke, single-cylinder
Fuel system	:	carburetor modified to direct injection system
Bore x stroke	:	52mm x 52mm
Ignition system	:	CDI AC
Cylinder capacity	:	110.4 cm^3
Compression ratio	:	7.1: 1
Fuel during testing	:	RON 90

The fuel system on this engine is modified to a direct injection fuel system. fuel from the fuel tank is pressed using an electric pump then sprayed directly into the combustion chamber through the injector of the direct injector type. The injection timing and injection duration are controlled by the Arduino Uno microcontroller board as an electronic control unit (ECU) where a protrusion mounted on the rotor functions as a proximity sensor trigger that will provide a signal to the Arduino Uno microcontroller board. The protrusion on the rotor triggers the start of the proximity reading and will be defined as the start of the injection timing. The injection duration is set through the Arduino Uno module by getting input from the throttle position sensor (TPS) rotation and the injector opening and closing duration as output.

2.2. *Experiment Setup*

The injection timing is adjusted by varying the placement of the protrusion, which functions as a proximity sensor trigger as an input for the injector to inject fuel, on the rotor using a protractor and assisted by a dial gauge to determine the piston reference at the *Top Dead Center* (TDC) position. The injection timing variations are 20° before Bottom Dead Center (bBDC), 0° Bottom Dead Center (BDC), and 20° after Bottom Dead Center (aBDC). The fuel pressure is 8.5 bar while the injection duration is set based on opening the throttle position sensor (TPS) from 0 - 100% opening, while the variation in injection duration is shown in Table 2.

The test is carried out by installing the engine on a motorcycle, then the engine is turned on and tested in engine speed variants (rpm) on the Dyno Dynamics Brand Model Lowboy Chassis AWD dynamometer chassis to measure engine performance in the form of torque and power (Figure 1). This test was carried out 3 times for each combination of data variations to determine the average value for each variation of the injection time and injection duration that had been determined.

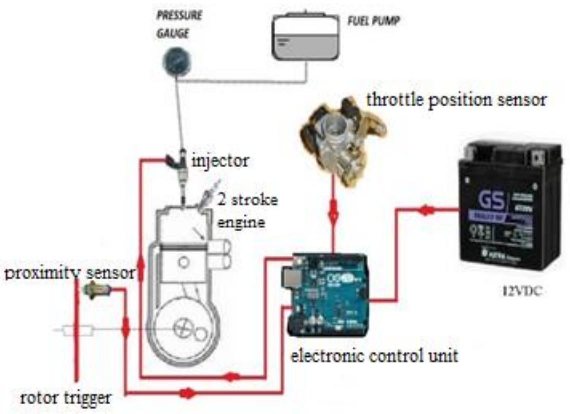

Figure 1. Experiment setup

3. Result and Discussion

3.1. *Experiment Results*

The experiment results using the chassis dynamometer obtained torque and power along with the increase in the engine revolution so that it will then be known the peak value of torque and power in each combination of injection timing and injection duration at 8.5 bar fuel pressure. The following is Table 3. peak values of torque and power for each setting variation.

Furthermore, based on the peak value of torque and power from each injection timing and injection duration, the settings that produce optimal performance will be selected.

3.2. *Discussion*

The peak torque from the combination of injection time (20° bBDC, 0° BDC, and 20° aBDC) and injection duration (A, B, and C) at a fuel pressure of 8.5 bar is shown in Figure 2.

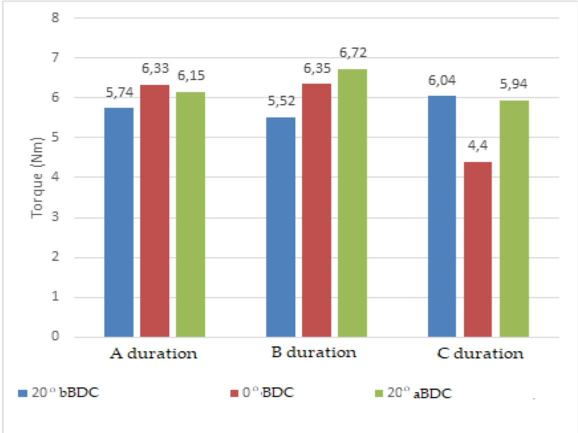

Figure 2. Peak torque

Figure 2 shows that the setting conditions of injection timing 20° aBDC and B injection duration have a peak torque of 6.72 Nm at an engine speed of 3140 rpm, which is the setting that produces the highest torque, while at injection timing 0° BDC and C injection duration has the lowest torque of 4.4 Nm at 3,250 rpm engine speed. The higher peak torque at the setting of 20° aBDC injection timing and B duration compared to the injection timing of 20° bBDC or 0° BDC is related to the mass of fuel trapped when the injection is made because it is known at the position of the piston before TDC in a 2-stroke engine, i.e. here at the injection timing of 20° bBDC or 0° BDC, some fuel is wasted through the exhaust port.

The right setting of injection timing and injection duration will result in large engine torque. This happens because the mass flow rate of the fuel that continues to increase with the right amount will overcome the load changes by enriching the fuel-air mixture. The rich fuel-air mixture (C duration) causes the torque to decrease, as well as the poor fuel-air mixture (A duration) the torque produced, cannot be maximized. So, in this study B duration is the optimal fuel-air mixture that produces the highest torque for this engine. When the injection dura-

Table 2. The variation in injection duration

No	TPS opening	A duration	B duration	C duration
1	0 – 25%	2.5 ms	3 ms	3.5 ms
2	26 – 50%	3.5 ms	3.75 ms	4 ms
3	51 – 75%	3.5 ms	3.75 ms	4 ms
4	76 – 100%	3.5 ms	3.75 ms	4 ms

Table 3. Peak values of torque and power for each setting variation

No	Injection timing	Injection duration	Fuel pressure	peak torque/engine speed, Nm/rpm	Peak power/engine speed, HP/rpm
1	20° bBDC	A duration	8.5 bar	6,33/3156	3.0/3931
2	20° bBDC	B duration	8.5 bar	6,09/3237	2,8/3237
3	20° bBDC	C duration	8.5 bar	6,04/2970	2,5/2970
4	0° BDC	A duration	8.5 bar	6,42/3137	3.0/3751
5	0° BDC	B duration	8.5 bar	6,55/3283	3,0/3321
6	0° BDC	C duration	8.5 bar	5,64/3129	2,5/3129
7	20° aBDC	A duration	8.5 bar	6,19/3298	3,0/3756
8	20° aBDC	B duration	8.5 bar	6,72/3140	3,0/2890
9	20° aBDC	C duration	8.5 bar	5,94/3196	2,7/3200

tion is combined with the fuel pressure, increasing the injection duration will increase the amount of fuel injected and the fuel pressure will increase the fuel atomization increasing torque and engine speed.

Figure 3 shows the peak power at each setting. The amount of power is proportional to the torque and speed produced by an engine, so that peak engine power can be obtained at high engine speeds where this can occur at large throttle openings. when the throttle opening is large, if too much fuel is injected, the combustion that occurs is incomplete, this will make the engine power decrease, this is what causes the average peak power at C duration to be the smallest, because at C duration is the duration for which the fuel-air mixture is the richest, especially at large throttle openings. Figure 3 shows the optimal peak power can be achieved at an injection timing of 20° aBDC at duration B where the peak power is 3 HP at 3140 rpm.

Figure 4 shows the performance curve of a 2-stroke direct injection spark ignition engine at a setting of injection timing 20° aBDC and B duration at a fuel pressure of 8.5 bar which results in optimal performance. The torque shown is directly related to the average effective pressure, as shown in the injection timing 20° aBDC setting and B duration, when the engine speed from low rpm to high rpm the brake mean effective pressure (BMEP) continues to grow, the torque also increases until it reaches peak torque of 6.72 at 3140 rpm. Torque will decrease after reaching its peak value at high rpm because the pressure above the piston is reduced, as well as the peak power produced which is 3 HP at 3140 rpm.

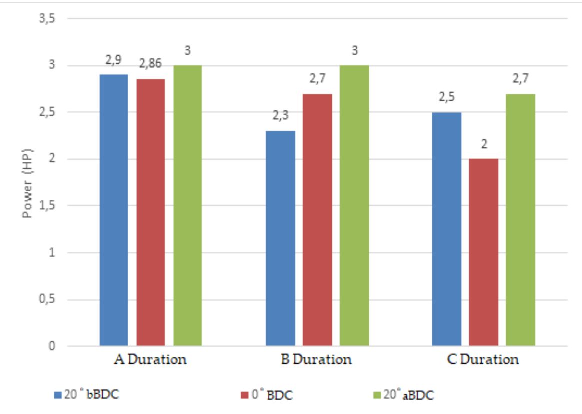

Figure 3. Peak power

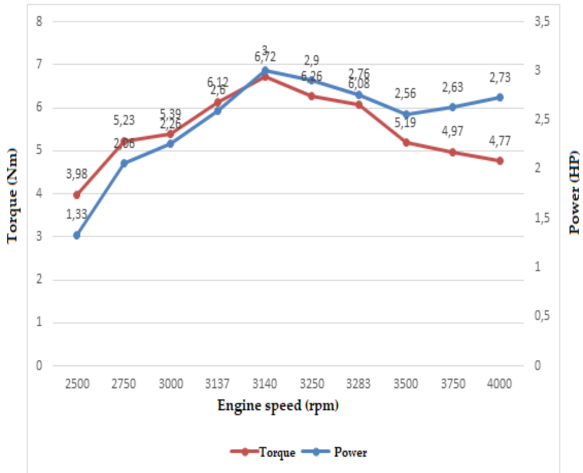

Figure 4. Optimal performance curve for setting injection timing 20° aBDC and B duration

Improperly changing the injection duration will reduce the torque generated by the engine. This happens because the fuel is not able to burn optimally. Too much fuel will result in a lack of oxygen that can react with the fuel so that the fuel is not able to burn completely. Meanwhile, too little fuel will make the combustion pressure drop, so that the torque produced also decreases.

Based on the data analysis of the effect of variations in injection timing and injection duration at an 8.5 bar fuel pressure on the performance characteristics produced by a 2-stroke direct injection spark ignition engine, the optimal injection timing, and injection duration settings are obtained, then these settings are used to program the injection timing and duration. using Arduino IDE software for prototype electronic control unit direct injection fuel system. Next, the flowchart for the prototype electronic control unit direct injection fuel system Arduino-based for 2-stroke engines Spark Ignition is shown in Figure 5.

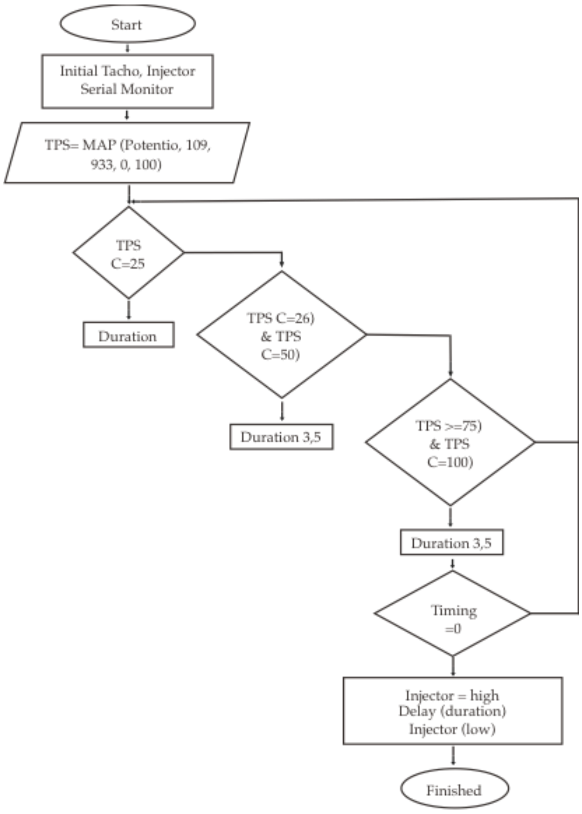

Figure 5. Flowchart for the prototype electronic control unit direct injection fuel system Arduino-based for 2-stroke engines Spark Ignition

According to the flow chart, the construction code will be as follow:

1. Input pin initialization, output pin, and the variable used to store the data for the steps in a different medium.
2. After completing Tacho and Injector initialization step, then followed by TPS reading.
3. TPS conversion process from potentiometer data to percentage throttle opening (system ready).
4. Next, the system starts to read the data from the sensor. Data reading from the sensor requires throttle opening percentage and rotor sensor injection timing.
5. After taking the input from the throttle opening and rotor sensor, the value is first compared with the TPS sensor percentage value. If the condition is true (TPS<=25) and the proximity sensor gets a trigger then the injector will spray fuel (duration 2.5s), if the throttle position sensor (TPS) is greater than >25 then it will go to the next step,
6. If the conditions are true TPS<=26 & <=50) and the proximity gets a trigger then the injector will spray fuel (duration 3.5s), if the throttle position sensor (TPS) is greater than >50 then it will go to the next step if the throttle position sensor (TPS) sensor is greater than >25 then it will go to the next step
7. If the conditions are true TPS<=75 & =100) and the proximity gets a trigger then the injector will spray fuel (duration 3.5s), If the TPS opening <75 it will return to step number 5 or 6.

If the proximity is logical (0/Low) then the injector is On according to the duration of the TPS (throttle opening) then the injector is Off.

4. Conclusion

The design of an Arduino-based direct injection fuel system electronic control unit prototype for the Spark Ignition 2-stroke engine is directed as a low-cost electronic control unit and is based on an open-source system so that it is easy to set up, proven to be fully functional, proven to be strong and experimental results meet the proposed

The mapping characteristics of the direct fuel injection system performance on a 2-stroke spark ignition engine are influenced by the injection timing and injection duration, which results in optimal performance by setting the injection timing 20º aBDC and B duration at a fuel pressure of 8.5 bar. This setting is then used as the basis for the instruction code in programming this ECU prototype.

This study, taking only two parameters, this electronic control unit system can be further modified with the addition of a more sophisticated design. Some advanced designs that can be added in the future are Air fuel ratio control and ignition control as well as sensor input parameters such as engine temperature and intake air sensors, oxygen sensors in exhaust, manifold air pressure sensors etc.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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