Simple Design of Electronics Engine Management for Motorcycle

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Abstract. The use of an electronic system to regulate the injection system is a solution that can improve the performance and fuel efficiency of an engine. However, conventional vehicles require retrofit to be able to use the electronic fuel injection (EFI) system. The design uses a microcontroller system with ARM32 architecture. The inputs used to determine the duration and timing of the injection are a crankshaft position sensor (CKP), throttle position sensor (TPS), manifold absolute pressure (MAP), air temperature sensor (ATS), and lambda sensor. Before the sensor signal enters the microcontroller, the signal is filtered using a low pass filter (LPF) with a cut-off point of 50Hz. The actuator system consists of an injector. While the ignition system can use a capacitor discharge ignition (CDI). The novelty in this design is that the type of sensor can be replaced with a resistant type sensor. So that there will be many variants of the fuel injection system tuning retrofit that can be done with conventional motors.

Keywords: EFI, TPS, MAP, IATS, LPF

1. Introduction
A combustion engine is a used to facilitate work, one of which is in terms of transportation. When the invention of the combustion engine for the first time, made a paradigm shift in solving human problems. The use of combustion engine is widely applied in agriculture, factories, and the most common is transportation. During its development, the combustion engine in the means of transportation develops faster with high efficiency.

The development of many combustion engine occurs in transportation, where controlling fuel injection and power regulation can be done by adjusting the timing of the injection and ignition signals. The duration of injection and ignition timing settings greatly affect the power and efficiency of the combustion engine. The further development, the combustion engine circulating on the road is still far behind. Some combustion engine has not been integrated with an electronic system for setting the injection system. So that many combustion engines operating on the road still have quite a low efficiency [1].

So that in this paper discusses the simple design of the electronic fuel injection system. Where the design is done by utilizing simple electronic components and a microcontroller system that is easy to program [2], [3]. In addition, reliability is very important to consider and be taken into account in designing electronic systems in combustion systems for retrofit engines [4], [5]. The engine to be retrofitted has a capacity above 100cc. This will determine the amount of efficiency that can be done on the combustion engine. The greater the capacity of the combustion engine, the greater the
efficiency effect of the engine using an electronic system. When using a combustion engine with a very small capacity, the electronic system affects the efficiency of the combustion engine less.

The development of the electronic system of the combustion engine requires sensors, control units, and actuators. The sensors are such as the crankshaft position sensor (CKP), throttle position sensor (TPS), manifold absolute pressure (MAP), air temperature sensor (ATS), engine temperature sensor (ETS), and lambda sensor [6], [7].

Meanwhile, the control unit system can use a microcontroller with an 8-bit to 32-bit architecture. This paper discusses the implementation of a control unit using a microcontroller with ARM32 architecture [6]. Meanwhile, the actuator only moves the relay, injector, and ignition system.

2. Design and study literature

Figure 1 shows a block diagram of the fuel injection electronic system being developed. Where there are 6 sensors used such as CKP, MAP, TPS, ATS, ETS, and lambda sensors.

![Figure 1. Block diagram of an electronic system design](image)

Where the function of the CKP sensor is to detect engine speed, the MAP sensor is used to measure the air pressure in the intake manifold, TPS is used to measure the rotation angle of the butterfly valve on the throttle body, ATS functions to measure the temperature of the air entering the intake manifold, ETS serves to measure the temperature of the engine when the engine is operating.

2.1 Parameter of engine

Table 1 shows the combustion engine parameters used in determining retrofitting for electronic fuel injection system design.

| Parameter       | Type     |
|-----------------|----------|
| Engine          | 4 stroke |
| Motor Stater    | DC motor |
| Capacity        | 125 cc   |
| Num cylinder    | 1        |
| Ratio           | 1 : 9,2  |
| Ignition type   | Spark    |

Where the engine uses a 4 stroke motor with a motor starter using a DC motor, a bore diameter of 12mm, a stroke height of 10mm, the number of engine cylinders 1, the compression ratio of the combustion engine of 9.8: 1, and the type of spark ignition.

2.2 Design of electronics
Electronic system parameters can be seen in Table 2. The parameters consist of sensors, control units, and actuators. The TPS sensor specifications used have a maximum rotation angle of 80°, the output voltage is analog with a range of 0 to 5V.

### Table 2. Specifications for sensors, control units and actuators

| Parameter   | Type           | Electric Output (V) |
|-------------|----------------|---------------------|
| TPS         | 0 - 80°        | 0 to 5.00           |
| MAP         | 0 - 100kPa     | 0 to 5.00           |
| ATS         | 0 - 80°C       | 0.28 - 3.11         |
| ETS         | 0 - 150°C      | 0.04 - 2.98         |
| CKP         | Reluctance     | 0 to 40.00          |
| O2 Sensor   | Narrow band    | 0 to 1.00           |
| Control Unit | ARM32          | 3.30                |
| Injector control | Pulse (MOSFET) | 12.00               |
| Igniter control | Pulse (MOSFET) | 12.0                |

2.3 Low pass filter

Figure 2 shows the LPF characteristic curve. Where the LPF design has a cut-off at a frequency of 50Hz. This is to reduce high-frequency noise. When frequencies above 10kHz enter, the gain value drops towards 0.

![Figure 2. LPF characteristics](image1)

![Figure 3. Design of LPF using 2nd order Sallen Key](image2)

Figure 3 shows the LPF design using the 2nd order Allen key. The design uses an operational amplifier (op-amp). The $V_{IN}$ value is the sensor voltage ($V_{Sen}$) added to the noise voltage ($V_{Noise}$). The equation for the $V_{IN}$ value can be seen in Equation (1).

$$V_{IN} = V_{Sen} + V_{Noise}$$  \(1\)

The size of $V_{Noise}$ adjusts the amount of interference that goes into the electronic system. The $V_{Noise}$ value has a high frequency. With high-frequency LPF coming from $V_{Noise}$. The frequency that can be passed can be determined using Equation (2).

$$f_c = \frac{1}{2\pi \sqrt{R_1R_2C_1C_2}}$$  \(2\)

While the $V_{OUT}$ from the LPF series in Figure 3 can be calculated from Equation (3).

$$V_{OUT} = V_{IN} \times Gain$$  \(3\)
Where the Gain value is equal to 1 when the $V_{IN}$ frequency is below $f_c$. Meanwhile, when the $V_{IN}$ frequency is above $f_c$, the Gain value will approach 0. So that the $V_{IN}$ frequency is above $f_c$, will issue $V_{OUT}$ close to 0V.

2.4 ARM32 as control unit.

Table 3 shows the microcontroller specifications used in the electronic fuel injection design.

| Parameter    | Description                  |
|--------------|------------------------------|
| Architecture | 32-bit ARM Cortex M-3        |
| Speed        | 72 MHz                       |
| Memory       | 64 kB FLASH / 20 kB RAM      |
| Voltage      | 3.6V                         |
| Resolusi ADC | 12-bit                       |
| Timer        | 16-bit                       |

Where the microcontroller uses the 32-bit ARM Cortex M3 architecture, has a clock speed of up to 72 MHz, a memory capacity of 64 kB for FLASH or main program storage, and 20 kB for RAM. The working voltage of the microcontroller is 3.60V. The ADC resolution on the microcontroller is 12-bit with a voltage range of 0-3.60V and data from 0 to 4095. The timer used for the counter and PWM is 16-bit.

2.5 Isolated gate driver

Figure 4 shows the isolated gate driver design which is used to control the injector and ignition coil.

![Figure 4. Isolated Gate Drive Design [9]](image)

Where the main component of the gate drive is the optocoupler. This is because the optocoupler has been separated by a light-emitting diode (LED) and a photodiode. When the LED is applied to the anode, the LED light illuminates the photodiode. The light signal captured by the photodiode triggers the upper and lower side of the transistor base in the push-pull topology. The push-pull output triggers the MOSFET on the injector control and the IGBT on the ignition coil control or as an igniter.

3 Design of electronics fuel injection

Figure 5 shows the EFI system design that will be carried out on a retrofit engine.
Figure 5. EFI design used in the study

Where, the ECU system that uses a microcontroller measures the incoming sensor voltage, such as the TPS, MAP, ATS, ETS, and lambda feedback sensors. The ECU controls an actuator such as an injector to adjust the duration and timing of fuel injection and the igniter which triggers the coil to increase the voltage so that it can spark sparks on the spark plug.

In the research process, of course, several steps need to be taken to obtain optimal results such as the sensor calibration process, determining the value of the fuel injection base map, the fuel injection timing base map, and the ignition timing base map.

3.1 Calibrating of sensor

Sensor calibration is used to match the readings with real parameters in the environment. There are 5 sensors that are carried out by the calibration process, namely TPS, MAP, ATS, ETS, and CKP.
Figure 10. Comparison of frequency and speed on engine

Figure 6 shows the TPS calibration. TPS is a sensor that reads the throttle body opening. Figure 7 shows the comparison between the air pressure and the voltage measured on the microcontroller (ECU). The MAP is a sensor used to measure the vacuum pressure in the intake manifold. Figure 8 shows the comparison between the air temperature and the voltage measured on the microcontroller (ECU). ATS is a sensor used to measure the temperature of the air that enters the intake manifold. Figure 9 shows the comparison between the temperature of the combustion engine and the voltage measured on the microcontroller (ECU). ETS is a sensor used to measure the temperature of the combustion engine. Figure 10 shows the comparison between the engine rotational speed and the measured frequency on the microcontroller (ECU). CKP is a sensor used to measure the rotational speed of the combustion engine crankshaft.

3.2 Base map duration
The determination of the value of the duration is determined using Equation (4).

\[
Req_{Fuel} \times 10 = \frac{T_p \times CID \times Air_{den}[MAP, T]}{(Ncyl \times AFR \times ln_{Flow})} \times \frac{1}{DP}
\]  

(4)

Where, \(Req_{Fuel}\) is computed injector open time in tenths of millisecond, \(T_p\) is 36,000,000 is the number of tenths of a millisecond in an hour, used to get the pounds per 1/10 millisecond from the pounds/hours rating of the injectors, \(CID\) is cubic inch displacement. \(Air_{den}\) is air density (pounds per cubic inch) at \(MAP\) pressure of 100 Kpa, air Temperature of 70 degrees F, and barometric pressure of 30.00 In HG, \(Ncyl\) is number of cylinders, \(ln_{Flow}\) is injector flow rate in pounds per hour, \(DP\) is injection divide the number for number of injections per engine cycle. The \(Air_{den}\) function (used above) is defined by:

\[
Air_{den}[MAP, T] = Cons \times \frac{273.13}{(T + 273.13)} \times \frac{MAP}{101.325}
\]  

(5)

Where, \(Cons\) is constanta from 1.2929, \(MAP\) is manifold air pressure in kPa, \(T\) is air temperature in degrees F.

3.2.1 Injection duration
Equation (6) shows the equation for adjusting the duration of fuel injection.

\[
PW = Req_{Fuel} \times VE \times MAP \times \gamma E + Accel + T_D
\]  

(6)

Where, \(Req_{Fuel}\) is the value of base injection duration (4.5mS), \(VE\) is volumetric efficiency, \(\gamma E\) is value of is the scaling factor applied to the \(Req_{Fuel}\) value, along with \(VE\)(RPM, MAP) and \(MAP\).
3.2.2 Compensation duration

Equation (7) shows the equation for compensation for the addition and reduction of fuel based on feedback from the sensor.

$$\gamma E = \left(\frac{\text{Warmup}}{100}\right) \times \left(\frac{O2}{100}\right) \times \left(\frac{AT}{100}\right)$$  (7)

Where Warmup is the warm-up enrichment value, O2 is the exhaust gas oxygen (EGO) adjustment based on the EGO sensor feedback and the EGO settings, AT is the adjustment for air density (based on the intake air temperature).

3.3 Base map timing injeksi

Base map timing is the timing of the fuel injection closed. This is determined based on the angle of the intake valve opening. When the fuel engine intake valve is closed, the injector must close. If the intake valve is still open and the injectors are still open, the fuel will be wasted. Equation (8) shows the determination of the fuel injection timing.

$$\alpha_{cl} = \text{Inj}_{cl}(RPM, MAP) + \gamma ET_{inj}$$  (8)

Where, $\alpha_{cl}$ is the injector close timing angle, $\text{Inj}_{cl}(RPM, MAP)$ is a table based on engine speed (rpm) and the amount of vacuum on the intake manifold (MAP), $\gamma ET$ is compensation based on some feedback from the sensor.

3.4 Base map ignition timing

The ignition timing base map has the same function as the injection timing base map. This is influenced by long dwelling on ignition and ignition point on engine combustion. So that the base map of the ignition timing is obtained from equation (9).

$$\alpha_{IG} = \text{IG}(RPM, MAP) + \gamma ET_{IG} + T_{Dwell}$$  (9)

Where, $\alpha_{IG}$ is the ignition angle of sparks, $\text{IG}(RPM, MAP)$ is a table based on engine speed (rpm) and the value of vacuum in the intake manifold (MAP), $\gamma ET_{IG}$ is compensation based on some feedback from the sensor, and $T_{Dwell}$ is the dwell time on the ignition system.

4 Conclusion

The design shows the use of a microcontroller as a control unit. The amount of gasoline that is injected is determined by several parameters such as butterfly valve opening, air pressure, air temperature, engine temperature, and the air and fuel mixture. All these parameters are measured using sensors. The sensor readings are entered into the equation on the microcontroller to be able to adjust the injection time and duration.

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