The Effect of Change in Injection Timing on Fuel Consumption of Garuda UNY Urban-19 Car Engine

Sutiman, I W Adiyasa, F A Prapsita and H Yudistira

Department of Automotive Engineering, Universitas Negeri Yogyakarta, Indonesia

Email: sutiman@uny.ac.id

Abstract. This study aims to optimize fuel consumption in the Garuda UNY Urban Gasoline-19 vehicle by changing the injection time mapping. Injection Timing Mapping using Programmable ECU software MegaSquirt III and Tuner Studio 3. Based on standard ECU data, Mapping Timing Injection Case 1 (IT-C1) and Timing Injection Case 2 (IT-C2) were generated. Performance tests are carried out using static tests in the laboratory and dynamic tests in the field. The application of IT-C2 resulted in the best reduction in fuel consumption, namely 12% in the static test and 11.08% in the dynamic test. The delay in initiation of injection results in less responsive acceleration.

1. Introduction

Energy optimization and efficiency is a challenge as well as an urgent need due to limited energy sources, especially those from fossil fuels. This challenge is actualized in various competitions that are participated in by students, including the Shell Eco-marathon (SEM). SEM is an annual competition that challenges students teams from around the world to design, build and drive energy-efficient vehicles. The competition aims to inspire the team to push the boundaries of fuel efficiency. To meet the demands of efficiency, development can focus on efforts to reduce loads, rolling resistance at vehicle speed, aerodynamic improvements to the vehicle body and optimizing the power generated by the engine.

The use of a motorbike engine (used motorcycle engine) which is applied to urban gasoline vehicles in SEM competitions requires adjustments in order to obtain optimal energy utilization. Improvements that can be made include modifications to the engine management system (EMS). The standard control system that is applied (to the used engine) is based on general use purposes where the electronic control unit (ECU) from the factory is not recommended for remapping. Implementation in competition requires adjustments so that fuel efficiency can be obtained optimally. These adjustments can be made, among others, by rearranging the fuel system which is applied through remapping and injecting fuel by utilizing the programmable ECU.
Figure 1. Fuel consumption and engine power, based on air fuel ratio [1].

Figure 1 shows the relationship between fuel consumption and engine power. The optimal consumption can be determined by designing the mixture at an ideal composition known as a stoichiometric mixture, where the mass of air to fuel is 14.7:1 [2], [3]. The actual combustion process in the engine cannot be done completely. Practically, this comparison has not been able to produce complete combustion by various engines [4]. The product from the exhaust still contains unburned fuel or as a volatile organic compound. This condition will also be strengthened by the addition of load on the engine (such as acceleration) and physical changes around the engine (temperature, humidity). In this situation, the fuel control system on the engine will provide a balance by compensating for the addition of fuel. The compensation that is applied (programmed) in the standard ECU aims to adjust to changes in loading, engine speed and environmental physical conditions in order to obtain optimal engine power. Compensation for the increase in injection duration such as in starter conditions, engine temperature when cold, when acceleration is accelerated by increasing injection duration. In relation to the need for fuel-efficient competition, these features should be minimized as much as possible so that fuel consumption is low.

Implementing a standard ECU (with complex control algorithms) presents its own difficulties in engine modification. The existence of protection from the factory [1], difficulties in software accessibility, the calibration process ultimately raises the need for a control system that has an open architecture so that it can be modified [5] as needed. For this reason, programmable ECUs are an alternative in an effort to modify the control system in order to obtain performance as needed.

2. Method
This study used an experimental approach, through remapping injection timing using the Programmable ECU MS-III to obtain the most efficient fuel consumption. Experiments were carried out using a single cylinder engine with the characteristics as shown in Table 1.

| NUMBER | PARAMETER                      | VALUE | UNIT |
|--------|--------------------------------|-------|------|
| 1      | Engine capacity                | 110   |Cc    |
| 2      | Number of cyl.                 | 1     |      |
| 3      | Compression ratio              | 9.3:1 |      |
| 4      | Torque                         | 8.76  |Nm    |
| 5      | Power                          | 6.56  |kW    |
| 6      | Fuel                           | Ron 98|      |
| 7      | Cyl Ø x stroke                 | 50 x 55.6| mm |
| 8      | Opening valve duration of camshaft | 242 | Degrees |
| 9      | Lambda sensor                  | Narrow|      |

The need for the air and fuel mixture is determined based on the lambda (\( \lambda \)) value. Comparison of the air-fuel mixture based on theoretical calculations is AFR\(_{theo}\), while the ratio of the mixture read on
the lambda sensor is $AFR_{act}$. To determine the amount of the mixture of fuel and air supplied to the engine, it can be calculated by equation (1-4).

$$\lambda = \frac{AFR_{act}}{AFR_{theo}}$$  \hspace{1cm} (1)

$$AFR_{act} = \frac{ma}{mf}$$  \hspace{1cm} (2)

$$mf = \frac{ma}{AFR_{act}}$$  \hspace{1cm} (3)

$$ma = \eta \rho a V d N / n$$  \hspace{1cm} (4)

Where, $ma$ is the mass of air, $mf$ is the mass of fuel (kg), $ma$ is the mass of air flowing into the engine, $mf$ is the mass flow of fuel entering the cylinder of the fuel engine, $\eta$ is a volumetric efficiency in a fuel engine, $\rho a$ is the density of air, $Vd$ is the cylinder volume of the combustion engine, the engine rotating speed is $N$, $n$ in a 4 stroke engine is 2 revolutions per cycle. Furthermore, the mass of air and mass of fuel can be determined:

$$mf = \frac{\dot{m}f}{(\dot{m}f + \dot{ma})} mm \eta AF$$  \hspace{1cm} (5)

$$mm = \frac{P(Vd + Vc)}{R \alpha Ta}$$  \hspace{1cm} (6)

$\eta AF$ is the efficiency of the air and fuel mixture traveling to the cylinder, and $mm$ is the mass of the particles that enter the cylinder. $P$ represents the combustion chamber pressure, is the volume of the compression chamber, which is the space above the piston, $Vd$ is the engine displacement volume, $R$ is a constant, $\alpha$ is the temperature inside. Determining the value of $Vd$ can use equation (7-8),

$$Vd = Nc \left(\frac{\pi}{4}\right) B^2 S$$  \hspace{1cm} (7)

$$Vc = \frac{Vd}{\sqrt{R}}$$  \hspace{1cm} (8)

The injection timing is determined based on the measurement of the intake valve opening on the engine. The opening of the intake valve starts at 324° after top dead centre (ATDC) and closes at 386° ATDC with an overlapping duration of 74°. The data is then analysed to determine the required injection timing changes. Mapping product that is selected must be able to meet the requirements worthy of running with static or dynamic load.

The static test was carried out in the laboratory and followed by a dynamic test on the road by applying the engine to the Garuda UNY Urban-19 car. Retrieval of test data on the dynamic test refers to the regulations set by the competition committee.

3. Result and Discussion

Initial injection timing data using standard ECU (genuine ECU / initial), initial injection timing was obtained at 380° after ATDC at idling position (with engine speed = 1200 rpm and fully closed throttle). At the time of increasing load and engine speed, injection timing can move forward up to 180° crankshaft angle at full loading. Furthermore, this data is used as the basis for developing mapping of injection timing with the help of Mega Squirt III software and programmable ECU Megasquirt III (MS-III).

Remapping of injection timing finally got two mapping cases that were tested and suitable for use, based on the consideration of ease of start and stability of performance when engine running tests are carried out using both static loads (in the laboratory) and running tests with reference to SEM regulations. Furthermore, this mapping is called Injection Timing-Case 1 (IT-C1) and Injection Timing-Case 2 (IT-C2). Figure 2 shows an IT-C1 graphic equipped with a graphic image of the MS-III software.
The characteristics of the IT-C1 describe the injection timing range that is tighter than the standard ECU. The initial injection timing starts at 365° ATDC, with the maximum advancement angle reaching 250° ATDC. The Mapping design on the IT-C2 is constructed with a wider injection timing angle with the initial timing 35° backwards compared to the IT-C1. The injection timing angle of advancement is also made more advanced, with a maximum advancement angle of 110° ATDC.

Changes in injection timing affect the calculation of the fuel injection duration into the injectors. The laboratory trials carried out resulted in fuel consumption measurement data on the three mappings that were applied, with five measurements, the average was obtained as shown in Figure 5.

From Figure 4, it can be seen that the IT-C1 mapping shows less fuel consumption compared to the standard. The resulting characteristics include the ease of starting and performance at loading which is more responsive than the standard ECU. The performance of fuel consumption compared to standard ECU shows better graphics at 3000 rpm, but is more wasteful at loading 4000 rpm and above. The
measurement results show that the average increase in fuel consumption is 1% more wasteful than the standard ECU.

In IT-C2 mapping, fuel consumption at overall loading shows better performance compared to standard ECU and IT-C2 mapping. Compared to standard ECUs, fuel consumption has improved, which is 12% more efficient. The vehicle performance on static loading shows that the IT-C2 mapping is lower than the other two mappings. IT-C1 is very sensitive to changes in engine temperature and acceleration which is less responsive. At low engine operating temperatures, the engine needs several starters to run and in this condition, acceleration must be carried out at a smooth pace.

The dynamic test was carried out on the road by applying the engine to the Garuda Urban UNY 2019 car. The test used a 10.33 km track. In accordance with SEM Asia 2019 regulations. Mapping on IT-C1 and IT-C2 produces different characters in terms of engine performance. The implementation of injection timing mapping in dynamic testing resulted in an improvement in the average consumption of 2.45% for the IT-C1 compared to standard ECUs. Unlike the static test results which tend to be the same value as the standard ECU, considering the test process is carried out at a fixed rotation, while the dynamic test, the engine tends to work at 2500 - 4000 rpm. The IT-C1 performance during acceleration gets better, especially at 4000 rpm and above.

| Attempt | ECU STD Cons | IT-C1 Cons | IT-C2 Cons |
|---------|--------------|------------|------------|
| 1       | 378          | 24.5       | 386        | 23.4       | 411        | 24         |
| 2       | 381          | 24.8       | 372        | 22.2       | 425        | 24.8       |
| 3       | 382          | 24.8       | 388        | 24         | 440        | 24.6       |
| 4       | 367          | 23.4       | 398        | 24.7       | 399        | 23.7       |

**Average**: 377 386 418.75

*Cons*: Fuel consumption (km/l); *Time*: in minutes

The best improvement in fuel consumption in the dynamic test was generated by the IT-C2 mapping with an average improvement in consumption of 11.08% compared to the standard ECU mapping. The drawback that stands out is the relatively longer travel time, and it becomes difficult to start when conditions are cold. The acceleration capability of the engine is reduced so that when driving, the throttle valve opening must be carried out at a smooth pace.

Mapping IT-C2 has an impact on changing fuel supply time (tends to be late because the initial timing is pushed back by 12° crankshaft) into the cylinder, which can affect acceleration capability. On the other hand, this change can reduce the effect of wasted fuel (hydrocarbon) into the exhaust pipe during valve overlapping. The delay in fuel injection will provide an opportunity for air to first enter the cylinder so that fuel supply is carried out when the exhaust valve is fully closed. In order to obtain more optimal results, this change in injection timing needs to be followed by an improvement in the airflow pattern in the intake manifold in order to increase the homogeneity of the mixture, and can result in improvements in loading with acceleration.

### 4. Conclusion

Mapping development using Megasquirt III was carried out by analysing valve duration and standard ECU performance. The injection timing change trial resulted in two mapping patterns, namely IT-C1 and IT-C2, which were suitable for use. The IT-C2 application resulted in fuel consumption improvements of 12% under static loading and 11.08% in dynamic tests. For IT-C1, fuel consumption tends to increase in the static test of the static test and vice versa in the dynamic test gives an average consumption improvement of 2.45%. Injectable Initial Timing retreating effects such as that of the IT-C2 reduce acceleration capability. For this reason, in order to obtain better performance, mapping changes need to be balanced with other improvements such as increased intake air turbulence.
5. Acknowledgments
Thanks to the Automotive Engineering department and the Garuda UNY team who have supported the research and the success in its implementation.

6. References
[1] I Wayan A, Yudianto A, Kurniadi N and Sutiman 2019 Applied programmable ECU on an internal combustion engine single cylinder 600 cc for Student Formula Japan Journal of Physics: Conference Series, 1273 p 012065
[2] Heywood 1998 Internal combustion engine fundamentals (New York: McGraw-Hill)
[3] Reif K Ed 2015 Gasoline Engine Management (Wiesbaden: Springer Fachmedien Wiesbaden)
[4] Muslim M T, Selamat H, Alimin A J, Mohd R N and Hushim M F 2014 A review on retrofit fuel injection technology for small carburetted motorcycle engines towards lower fuel consumption and cleaner exhaust emission Renewable and Sustainable Energy Reviews 35 pp 279–284
[5] Ashok B, Denis A S and Ramesh K C 2016 A review on control system architecture of a SI engine management system Annual Reviews in Control 41 pp 94–118