Applied programmable ECU on an internal combustion engine single cylinder 600 cc for Student Formula Japan

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Abstract. Student formula competition requires modification of the intake manifold hole by 20 mm. The internal combustion engine used has a capacity of 600 cc and an intake hole of 45 mm. The intake hole reduction affects the performance of the internal combustion engine. The ratio of the amount of air that is too small causes a decrease in engine performance. Ignition remapping is needed and fuel injection on the internal combustion engine. In the remapping process, the ratio of air and fuel is adjusted to the needs. The standard ECU on an internal combustion engine cannot be remapped. So the standard ECU on internal combustion engines is replaced using Motec M400. The parameters on the engine are only added to the camshaft sensor to determine the ignition timing and injection. Other sensors such as throttle position sensor, manifold absolute pressure, intake air temperature sensor, and engine temperature are used to determine ignition mapping parameters, fuel injection, and compensation for cranking, idle, and acceleration requirements. Tests obtained ignition remapping and fuel injection on internal combustion engines using ECU.

1. Introduction

Student formula is a competition for 4-wheel design racing vehicles an internal combustion engine with a capacity of 450-700cc. The design is adjusted to the regulations issued by the organizing committee. Problems in the engine design when the intake manifold hole is decreased. Reduction in hole diameter in the intake manifold to limiting the power the internal combustion engine. Changes the diameter of the intake manifold hole cause the ratio of air intake the internal combustion engine to be small. The small amount of air intake the internal combustion engine causes fuel emissions to increase. The increase in emissions causes engine performance to decrease and fuel consumption to increase. This is very inefficient.

Figure 1 shows the effect of stoichiometric values between power and fuel consumption on internal combustion engines. When the stoichiometric value is at a value of 1, the engine shows performance with optimum fuel consumption. When the air ratio is greater than fuel, the fuel consumption is lower. But the performance of the internal combustion engine decreases. Conversely, when the air ratio is smaller than fuel, the performance of the internal combustion engine increases. But the fuel consumption becomes large [1].
Keeping the air and fuel ratio at stoichiometry values, can be done by using ECU remapping [1]. The standard ECU feature from the factory does not recommend remapping. That is because the protection is done at the factory to anticipate the occurrence of damage to the combustion engine. So the programmable ECU is used to do ignition remapping and fuel on the internal combustion engine [2]. The results in the application of the ECU programmable obtained mapping of ignition, fuel injection, and fuel compensation when cranking, idle, acceleration, and temperature [3].

![Stoichiometric relationship with power and fuel consumption on internal combustion engines](image)

**Figure 1.** Stoichiometric relationship with power and fuel consumption on internal combustion engines

2. Design Experiment

The experimental design was carried out based on regulations issued from SAE international for the Student Formula Japan event.

2.1. Engine setup

Table 1 shows the specifications of the engine used.

| Number | Parameter                        | Value | Unit |
|--------|----------------------------------|-------|------|
| 1      | Capacity Engine                  | 600   | Cc   |
| 2      | Num Cylinder                     | 1     |      |
| 3      | Ratio Compression                | 12.4 : 1 |    |
| 4      | Fuel                             | RON 98 |      |
| 5      | Power                            | 46    | HP   |
| 6      | Torque                           | 35    | ft-lb|
| 7      | Diameter of Intake Manifold      | 45    | mm   |
| 8      | Air Cooler Capacity              | 3     | Litre|

To determine the amount of air and fuel entering the internal combustion engine can be calculated using the equation (1-4).

\[
\lambda = \frac{AFR_{act}}{AFR_{theo}} \tag{1}
\]

\[
AFR_{act} = \frac{m_a}{m_f} \tag{2}
\]

\[
\dot{m}_f = \frac{m_a}{AFR_{act}} \tag{3}
\]

\[
\dot{m}_a = \eta_a \rho_a V_a N / n \tag{4}
\]
Where, \( \lambda \) shows the lambda value or stoichiometry value when the ratio of air and fuel equals 1, \( AFR_{act} \) is the ratio of air and fuel mixture from the lambda sensor readings, \( AFR_{theo} \) is the ratio of air and fuel mixture from theoretical calculations, \( m_a \) is the mass of air (kg), \( m_f \) is the mass of fuel (kg), \( \dot{m}_a \) is the mass flow of air that enters the engine of the combustion engine, \( \dot{m}_f \) is the mass flow of fuel that enters the fuel engine cylinder, \( \eta_a \) is an efficiency volumetric on a fuel engine, \( \rho_a \) is the density of air (kg/m³), \( V_d \) is a combustion engine cylinder volume (m³/cycle), \( N \) engine rotating speed (rev/sec), \( n \) on a single cylinder engine is 2 rev/cycle. Based on the equation of air and fuel ratio, air mass and fuel mass are obtained from the equation (5).

\[
\dot{m}_f = \frac{\dot{m}_f}{(\dot{m}_f + m_a)} m_m \eta_{AF} \tag{5}
\]

Where \( m_m \) is the mass of particles that can enter the combustion chamber, \( \eta_{AF} \) is the efficiency of air and fuel that can enter the combustion chamber. In general, the value of \( \eta_{AF} \) is assumed to be the percentage of combustion chamber volume minus the remaining combustion results. When the exhaust cycle, the combustion results will come out through the exhaust valve. However, when the exhaust valve is closed, there is still residual combustion left in the combustion chamber, so that \( \eta_{AF} \) can be assumed. Whereas to get the value \( m_m \) obtained equation (6),

\[
m_m = P(V_d + V_c)/R_aT_a \tag{6}
\]

Where \( P \) is the pressure (kPa) in the combustion chamber, \( V_d \) the engine displacement volume (m³) on the cylinder, \( V_c \) the volume of the engine compress (m³) on the cylinder head block, \( R \) is a constant (0.287 kJ/kg-K), \( T \) is the temperature (K) that is in the cylinder. The \( V_d \) value can be calculated using equation (7-8),

\[
V_d = N_c(\pi/4)B^2S \tag{7}
\]
\[
V_c = \frac{V_d}{CR} \tag{8}
\]

2.2. ECU Motec

Ignition and fuel injection remapping using a 3D table lookup method [4], [5]. Each value in the table shows the output value to set the ignition timing, injection timing, and injection duration. To get the injection duration, you can use equation (9).

\[
Fuel = \frac{36000000 \times V_d \times \rho_a}{(N \times AFR \times f_{inj})/Pulse} \tag{9}
\]

Where fuel is the value of the fuel that should be injected, 36000000 is the number of pulses of 10 kHz within 1 hour, \( f_{inj} \) is the injection frequency, \( Pulse \) is the number of pulses in the control unit. Airflow \( \rho_a \) can be determined using equation (10).

\[
\rho_a(MAP, T_a) = 1.2929 \times \frac{273.13}{(T_e + 273.13)} \times \frac{MAP}{101,325} \tag{10}
\]

Where the \( MAP \) is the result of reading from the sensor manifold absolute pressure, \( T_a \) is the temperature of the air entering the intake manifold, \( T_e \) is the engine temperature. To find the width of the signaling pulse on the injection is obtained from equation (11).

\[
PW = Fuel \times VE \times MAP \times Comp + T_{delay} \tag{11}
\]

Where \( PW \) is the pulse width, \( VE \) is the data in the fuel table, \( Comp \) is the compensation of the injection value based on changes in parameters, \( T_{delay} \) is the delay time on the injector.
2.3. Sensor
The sensor is a component that is able to convert an energy or unit into an electrical signal. Changes in electrical signals are used to measure natural signal units such as distance, pressure, temperature, and others. The combustion engine uses many sensors to observe several parameters such as air temperature, engine fuel temperature, pressure that occurs in the intake manifold, changes in throttle opening, piston position [2], [3]. The results of the installation are used to determine the ignition timing, injection timing, and injection duration. The sensor used in the combustion engine can be seen in table 2. There are 7 sensors used in the combustion engine.

| Number | Sensor                        | Type            | Function                                           |
|--------|-------------------------------|-----------------|---------------------------------------------------|
| 1      | Crankshaft sensor             | Magnetic        | Determine ignition and fuel injection timing      |
| 2      | Camshaft sensor               | Magnetic        | Determine ignition timing and injection duration  |
| 3      | Throttle Position Sensor      | Potentiometer   | Determine timing ignition and duration injection (low speed) |
| 4      | Manifold Absolute Pressure    | Absolute Pressure| Determine duration injection (high speed)          |
| 5      | Intake Air Temperature        | -               | Determine compensation of fuel injection duration |
| 6      | Engine Temperature            | -               | Determine compensation of fuel injection duration |
| 7      | Lambda Sensor                 | Wideband        | Monitoring air fuel ratio                         |

3. Result and Discussions

3.1. Base ignition mapping
Figure 2 shows the mapping of the ignition timing using the ECU Motec M400. Engine speed is at 2500 RPM when idle. When conditions are idle, the throttle opening is 0%. While the ignition timing is at 29° BTDC. As speed increases, ignition timing increases.

3.2. Base fuel mapping
Figure 3 shows the mapping of fuel injection duration below 6000 RPM. Table base uses engine speed input and throttle opening. Throttle-based settings to get faster engine speed response. The amount of fuel injection to achieve a fast response is needed.

![Figure 3. Injection duration mapping at speeds below 6000 RPM using Motec M400 ECU](image)

### 3.3. Second base fuel mapping
Figure 4 shows the mapping of fuel injection duration at speeds above 6000 RPM. Table base uses engine speed input and air pressure in the intake manifold. An air pressure based setting in the intake manifold to get the optimum air and fuel mixture in the stoichiometric area. At speeds above 6000 RPM, air flow into the intake manifold is stable.

![Figure 4. Injection duration mapping at speeds above 6000 RPM using Motec M400 ECU](image)

### 3.4. Compensation cranking
Figure 5 shows the compensation for adding fuel to the engine when starting. Table mapping is based on the time and temperature of the combustion engine. When the engine is cold in the first second, the fuel injection duration is added. When passing second 2 up, the fuel injection duration is reduced. When the engine temperature is above 50°C, the injection duration is also reduced.

![Figure 5. Compensation cranking](image)
Figure 5. Fuel compensation on the engine when cranking

3.5. Compensation idle
Figure 6 shows fuel compensation based on air temperature in the intake manifold. The lower the air temperature, the greater the addition of fuel. This is to facilitate combustion in the engine combustion chamber. The greater the air temperature, the injection duration is reduced. The greater the air temperature, the smaller the air volume, so the fuel injection duration must be reduced to achieve stoichiometry values.

![Figure 6. Fuel compensation based on air temperature on the intake manifold](image1)

![Figure 7. Fuel compensation based on fuel engine temperature](image2)

Figure 7 shows the compensation for adding fuel based on the temperature of the combustion engine. The lower the engine temperature, the greater the addition of fuel. This is to accelerate the achievement of working temperatures on the combustion engine.

4. Conclusion
The results of remapping obtained mapping table for ignition timing, injection timing, and injection duration. There is fuel compensation in starting conditions to optimize ignition of the engine. The addition of injection duration is not only based on remapping tables, but also some parameters such as changes in air temperature in the intake manifold and changes in the temperature of the fuel engine.

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