International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

System Identification on Engine Air Fuel Ratio Control System

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Abstract: Traditional engine use carburetor instead of fuel injection. The carburetor uses direct mixing of air and fuel into the engine compare to fuel injection that had a control system that adjust the volume of air to fuel mixture entering the engine. The fuel consumption is depending on the air to fuel ratio that is being injected into engine by injectors. Nowadays the price of the fossil fuel had been increase drastically compared to the last five years. The combustion of the engine has a major impact to the value of the Air-Fuel Ratio (AFR). When the air to fuel ratio is not close to the stoichiometry value, then the fuel consumption is not economical, and the engine is not in their optimum condition. An optimum and economical engine performance give a result in a decrease in fuel consumption thus reducing the carbon monoxide (CO) and hydrocarbon (HC) into the atmosphere. Thus, this paper presents the system identification on fuel control system for controlling the air fuel ratio. Hence the parameters and relationship of the air fuel ratio can be reconnoitering.

Index Terms: ***Air fuel ratio; Control system; System identification.***

I. INTRODUCTION

Electronic Fuel Control System (EFCS) is the main system of the Fuel Control System. The system controls the flow of the air to fuel ratio that is needed by the engine to run. The primary function of the system is to determine the accuracy of the mass of the air flow rate injected to the engine. The system will regulate or inject the fuel accurately so the ration of the air to fuel injected to the cylinder is close or equal to the stoichiometry value of 14.7. This value gives a meaning of 14.7 kg of air to 1 kg of fuel [1]. This stoichiometry value only valid for the carbon-based fuel and not to the biometric fuel.

There are two types of device used to mix the mixture of air and fuel for ignition process. They are carburetor and fuel injection. Carburetor was invented by Karl Benz in 1885 [2]. The carburetor only relied on gathering fuel vapor by air flowing over the liquid fuel. The carburetor utilizes the Bernoulli principle for the air flow. The carburetor was widely used from 1980s until 1996 [3].

The fuel injection (FI) development was started in 1893 when Rudolph Diesel work with Augsburg and Krupp to develop more efficient internal combustion engine (Deluca). However, the fuel injection was not introduced to the automotive world until 1967 when Bosch make the first successful mass production of electronic fuel injection system. The first automobile that use fuel injection system is Volkswagen 1600 [4]. The fuel injection is even used until nowadays.

This is due to the fuel injection give an economical fuel consumption and emission. This is due to more precise control of the mixture of air and fuel injected. Other than that, FI also can be adjusted thus making the fuel delivery to match the driver demand compare to carburetor that does not allowed changes in air or fuel temperature [3]. Thus, using fuel injection, the release of carbon monoxide(CO) and hydrocarbon (HC) into the atmosphere can be reduces due to less fuel consumption.

As an example, let take Perodua Bezza (1.3 cc) and Proton Saga (1.3 cc) in term of fuel consumption. For Perodua Bezza, the average fuel consumption is around 4.6 litter per 100km [6] meanwhile for Proton Saga, the average fuel consumption is around 5.4 litter per 100 km [5]. This has shown that even both manufacture use fuel injection system, but the fuel consumption is different. Thus, this had proven that a different type of fuel control system had been used by both companies.

Air-Fuel Ratio (AFR) is the ratio of the mass of air to fuel present during combustion process. The AFR is important for controlling the performance and emission control of the engine. Lambda sensor/ Oxygen sensor is used to determine the stoichiometric value and operation when measuring the AFR. The difference in oxygen pressure lead to difference voltage that related to the difference in partial pressure. At rich ratio of AFR, the high output (V just below 1 V) is shown by the sensor. Meanwhile for the lean mixture, voltage fall to order of 0.1 V.

From that sensor data, the voltage value can be converted to display the AFR value on the gauge meter. This will become the real time data. From that data then the comparison between simulation data and real time data can be done. Thus, the result of the enhancement and verify of the system can be achieved.

Traditional engine use carburetor instates of fuel injection. The carburetor uses direct mixing of air and fuel into the engine compare to fuel injection that had a control system that adjust the volume of air to fuel mixture entering the engine. The fuel consumption is depending on the air to fuel ratio that is being injected into engine by injectors.

Revised Manuscript Received on October 30, 2019.

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Nowadays the price of the fossil fuel had been increase drastically compared to the last 5 years. Most of the users they wanted to reduce their cost of living. One way of reducing their cost of living is by reducing the amount of money spend on the gas/ petrol. The combustion of the engine has a major impact to the value of the Air-Fuel Ratio (AFR) [7].

When the air to fuel ratio is not close to the stoichiometry value, then the fuel consumption is not economical, and the engine is not in their optimum condition [8]. An optimum and economical engine performance give a result in a decrease in fuel consumption thus reducing the carbon monoxide (CO) and hydrocarbon (HC) into the atmosphere [9]. Thus, an effective fuel control system needs to be investigated for controlling the air fuel ratio. Hence the parameters and relationship of the air fuel ratio can be reconnoitered.

The type of engine model used for this study is Spark Ignition Engine (SI). Spark ignition engine is a system in which the air- fuel mixture in the combustion chamber of an engine is ignited using a spark plug. The system uses an electrical field induce by the magnet (also call coil) in the engine system. A spark ignition (SI) engine is capable to operate with a leaner air-fuel mixture to gain a stable combustion and ignition performance. The SI engine have a moderate compression ratio and the ignition is ignite by electric arching compare to diesel engine which had charge heating. This make the SI engine is less expensive and produce high power output [10].

There are four main sensors that are used in the EFCS which are the Throttle sensor, Manifold Absolute Pressure (MAP) sensor, Oxygen sensor and Engine Speed sensor. These sensors had their own characteristic and input value for the EFCS. However, for the air fuel ratio, the main component is the oxygen sensor/lambda sensor.

The warming up state is ignored due to the temperature for the engine to become hot is not necessary for the simulation process. However, for the real time experiment, the state needs to be considered. Since the modelling is only for the idle condition of the engine, thus the minimum rpm of the engine is only to be set as 1200 rpm which is the standard factory made. Meanwhile for the maximum RPM during idle condition is 2800 rpm. This is the highest of the engine timing condition for the engine to run at idle condition.

The experiment only focuses on idle condition of the engine and this meant that the running state of the engine is not applied. This will eliminate the other factors of car weight, friction force and gear ratio of the car. The ideal value of the stoichiometry value is set to be 14.6 However, for real time data, the condition of real world needs to be taken. Thus, the stoichiometry value can be in range of 13.0 until 16.0 which let the 13 to be lean and 16 to be rich.

II. EXPERIMENTAL

The experiment is based on the Simulink simulation of the modelling of a fault-tolerant fuel control system from the Matlab simulation model. The model can be retrieving from the command of sldemo_fuelsys . The value for the engine's rps is set to be 120 rps, 200 rps and 300 rps which are equivalent to 1145.93 rpm, 1909.89 rpm and 2864.83 rpm.

Based on the Fig. 1, system identification starts when the user opens the system identification graphical user interface (GUI) from the Matlab command window. Once the system identification GUI has appeared, next the data need to be imported into the command window as it will be used in the system identification process [11].

The data then is call into the system identification GUI and the model and parameters need to be selected form the system identification GUI. Once it is set, the model is plot then the user will check for the most suitable model that can be selected for the result. Once the model is selected, the transfer function will be exported into the workspace so the mathematical equation model can be shown and recorded.
Next, the step info of the transfer function can be check, selected and recorded as the result of the system identification. Lastly, bode plot and root locus can be plot and recorded as the result.

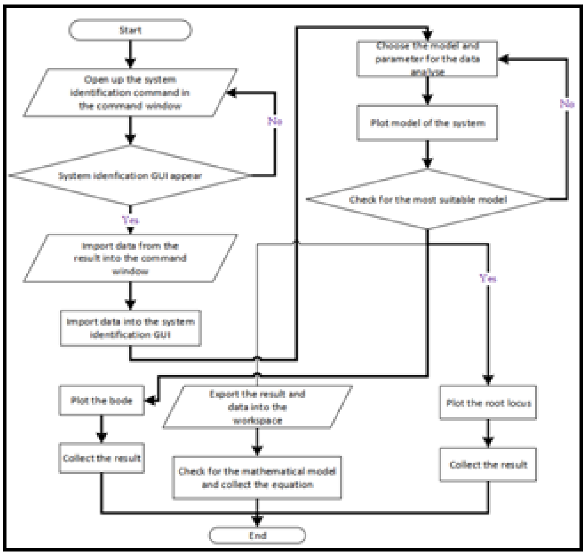

Fig. 1 System identification flowchart

Fig. 2 shows the wiring diagram of the oxygen sensor to the AFR meter for the connection purposes. Thus, the installation of the sensor to the meter just following the connection of the wire.

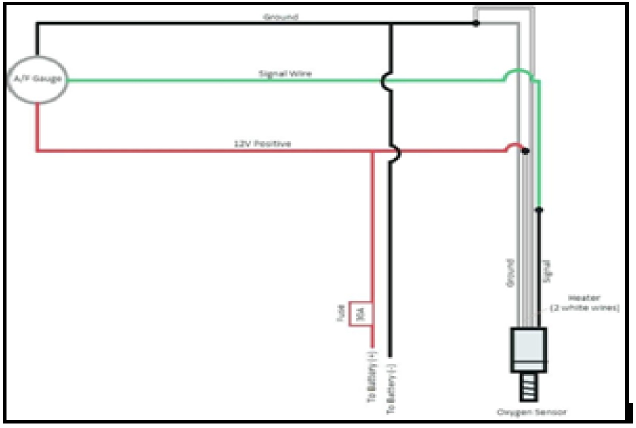

Fig. 2 wiring diagram of the oxygen sensor to the AFR meter

Fig. 3 show the actual AFR meter that is used to collect the real time data from 1.3 cc engine. The meter only has a scale of 0.1 and it is a standard for any type of AFR meter used in commercial car.

Fig. 3 AFR Meter

Fig. 4 is one type of engine for 1.3 cc (cubic centimeter). This engine is used on Perodua Myvi car type and it is using a fuel injection system. The real time data is based on this type of engine as the simulation also used the same cubic centimeter (cc).

Fig. 4 3-16V twin cam engine

III. RESULTS AND DISCUSSION

Referring to Fig. 5 and 6, the transfer function of air fuel ratio for 120 rps simulation, the poles are 12 and the zeros is 10. Thus, the mathematical equation is represented as:

(-0.4 s^10 + 0.01 s^9 - 0.003 s^8 + 0.0001 s^7 - 6.6e-06 s^6 + 2.6e-07 s^5 - 4.0e-09 s^4 + 1.2e-10 s^3 - 6.3e-13 s^2 + 1.5e-14 s - 2.9e-18)

(s^12 + 0.22 s^11 + 0.03 s^10 + 0.003 s^9 + 0.0002 s^8 + 9.9e-06 s^7 + 4.3e-07 s^6 + 1.5e-08 s^5 + 3.5e-10 s^4 + 6.6e-12 s^3 + 1.05e-13 s^2 + 8.2e-16 s + 1.007e-17).

For the transfer function of air fuel ratio for 200 rps simulation, the poles are 9 and the zeros is 8. Thus, the mathematical equation is represented as:

(-26.66 s^8 + 0.3496 s^7 - 0.184 s^6 + 0.00223 s^5 - 0.0003496 s^4 + 3.364e-06 s^3 - 1.428e-07 s^2 + 5.106e-10 s - 3.664e-14)

(s^9 + 0.7035 s^8 + 0.0355 s^7 + 0.005004 s^6 + 0.0002015 s^5 + 9.83e-06 s^4 + 3.383e-07 s^3 + 3.869e-09 s^2 + 9.761e-11 s + 3.386e-13)

For the transfer function of air fuel ratio for 300 rps simulation, the poles are 4 and the zeros is 3. Thus, the mathematical equation is represented as:

(7.584 s^3 - 0.1316 s^2 + 0.0001329 s + 3.398e-08)

(s^4 + 1.439 s^3 + 0.04155 s^2 + 0.0001223 s + 9.92e-08)

Based on Tab. 1, the AFR value is slightly lower compare to the simulation result. This is due to some limitation that occur during the experiment. However, the data is still in a valid range of the stoichiometry value.

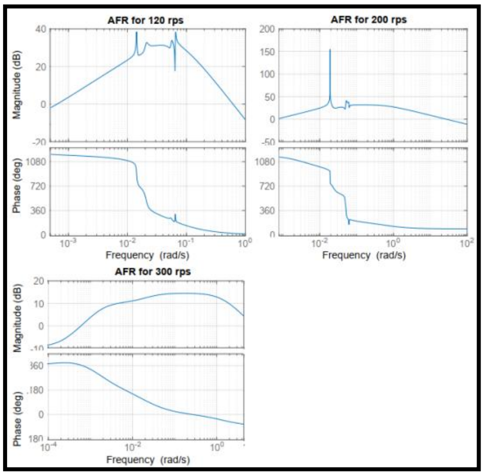

Fig. 5 Bode plot for 120, 200 and 300 rps of air fuel ratio

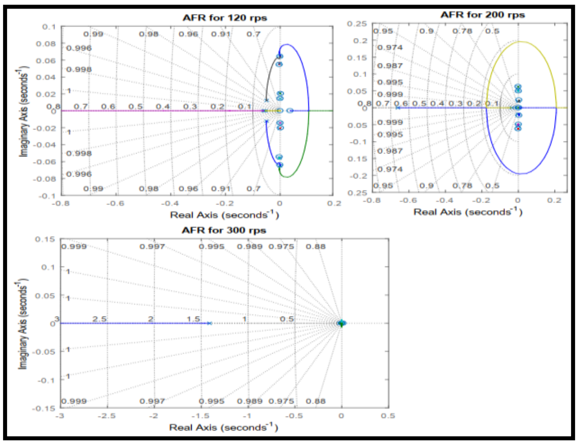

Fig. 6 Root locus for 120, 200 and 300 rps of air fuel ratio

Table. 1 Real time experiment data from 1.3-16V twin cam engine

RPS	AFR Value
120	10.0
160	10.5
180	11.6
200	12.8
260	13.7
300	13.9

Tab. 2 show a result for the step-response characteristic of the system identification for the best fit model out using the transfer function. Therefore, by comparing the rise time and overshoot, the most optimum system can be selected.

The most suitable condition for the starting and idle condition for the engine is for the speed to be at range of 120 rps.

Table. 2 Step-response characteristics for Air Fuel Ratio (AFR) model

(RPS)	Step-response characteristics for dynamic system model	
120	Rise Time (s)	0.9968
	Settling Time (s)	1.1322 x10^{4}
	Settling Min (s)	-9.9821
	Settling Max (s)	20.4271
	Overshoot	3.3421 x10^{3}
	Undershoot	7.0438 x10^{3}
	Peak Time (s)	61.3210
200	Rise Time (s)	2.4098 x10^{3}
	Settling Time (s)	2.0019 x10^{9}
	Settling Min (s)	-10.9138
	Settling Max (s)	10.6763
	Overshoot	9.9838 x10^{3}
	Undershoot	9.8644 x10^{3}
	Peak Time (s)	1.8916 x10^{5}
300	Rise Time (s)	0.3751
	Settling Time (s)	3.6211 x10^{3}
	Settling Min (s)	-2.5825
	Settling Max (s)	4.1978
	Overshoot	1.1254 x10^{3}
	Undershoot	753.8242
	Peak Time (s)	5.7450

During the speeding, the most suitable speed needs to be at 300 rps. This is based on the overshoot value is at the lowest. Therefore, the amount of the fuel can be save thus making the fuel consumption to be at optimum. Based on this condition, the amount of the carbon release into the air will be at the lowest compare to other speeds. Thus, this will reduce the amount of the gas release making the pollution will be reduces and the greenhouse effect will be reducing.

IV. CONCLUSION

As conclusion, the model for the fault-tolerant fuel control system is enhanced by introduce the system identification to the data analysis. The system identification had proven that the lowest overshoot with an appropriate rise time is for the 120 rps where for the speeding condition the suitable speed is the 300 rps. This result also supported by the poles and zeros plot of the system that indicate that the system is in marginally stable state. The state is due to the engine operating system that allow the mixture of fuel and oxygen into the block cylinder.

By using the real time data from the experiment of the 1.3-16V twin cam engine, the performance of the system can be analyzing. By referring to the percentage error between the simulation result and the actual result, for the 120 rps the percentage error is 31.9% and for the 300 rps the percentage error is 4.79%. The result is in the acceptable range thus making the system is acceptable for real world usage.

There are a few recommendations that need to be taken in order to improve the experiment and the data collected. The first recommendation is usage of data logger for the real time testing. By using the data logger, a much more accurate data can be recorded thus it will produce a much more accurate result for the comparison and analysis between the actual data and simulation data. An accurate data will be able to produce a much more accurate result for the percentage error between the system and the actual testing.

Secondly, the AFR or lambda sensor need to be embedded at the exhaust valve instead of at the end of exhaust gas chamber. This will make the result to produce accurate value of the system due to less byproduct of the combustion had been filter before it is exiting the gas chamber. If the sensor is put at the exhaust valve, the unfiltered gas can be detected, and a much more accurate result will be collected.

Thirdly is applying for the warming up condition instead of ignoring them. Amount of hydrocarbon and carbon monoxide release into the air is different in those condition. Mostly the amount of hydrocarbon and carbon monoxide release are much higher after the warming up condition comparing to the starting up state.

Next is the AFR meter need to have a much more decimal scale instead of 0.1 scale. The scale will provide a reading with more accurate result because with the simulation, it gives a data of 0.001 scale. Thus, the meter used need to have at least 0.01 scale.

Other than that, the next experiment can be done by comparing the carburetor system with the fuel injection system. Which one between them that will give out the most optimum value for the fuel consumption and the amount of gas release into the atmosphere.

ACKNOWLEDGMENT

Foremost, I would like to express my sincere gratitude to my fellow colleagues from Universiti Kuala Lumpur Malaysian Institute of Marine Engineering Technology (UniKL MIMET), Mohd Harkikie Fitri Abd Karim and Muhammad Fikri Doni for the continuous support in this research and development project. Highest appreciation for their patience, motivation, enthusiasm, and immense knowledge. Deepest gratitude also to our institute, UniKL MIMET to support in funding the development of the project.

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