TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 14, No. 2, May 2015, pp. 280 ~ 287
DOI: 10.11591/telkomnika.v14i2.7597

Power Optimization of Spark Ignition Engine by Fuzzy Logic Ignition Controller Based on Knock Detection

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Abstract

Spark ignition engines have many advantages, but to increase the power and efficiency, they have a problem to set the right ignition timing, at which the maximum power can be achieved. In reality, the optimum ignition timing is immediately prior to, or close to knock (detonation). On the other hand, the value of this optimum ignition timing is dependent primarily on the rotation of the crank shaft and the level of throttle openings. To provide the right timing, it is very difficult if only using mechanical control system as found in conventional engines. So, in this study, a new electro-mechanical method based on Fuzzy Logic Ignition Controller (FLIC) which follows the pattern of the timing in the knock chart was created. In fact the results of the FLIC study, was able to provide correction for each ignition, according to the data on the chart of the optimal ignition timings for all combinations of engine rotations and throttle openings. From the final data recorded, it can be said that the FLIC able to push the power up to 15% above normal, while eliminating the knock.

***Keywords**: knock, detonation, spark advance, fuzzy logic control, engine power*

1. Introduction

The power from the engine depends on the air to fuel ratio, the quality of the fuel mix, the turbulence level of the flow, combustion timing, the temperature in the combustion chamber, the engine cooling and lubrication systems, and so on. [1]. However, the biggest challenge is how to get the optimal ignition timing in order to get best perform, but it is always faced the problem of knock, which is a serious problem until today.

Control of the optimal ignition timing (spark advance) is very complicated because of something depends on the current operating conditions, namely: engine speed, throttle opening (load), engine temperature, fuel type, and so on. So, at any time, when the operating conditions change, the spark advance must also change. In a conventional engine, control is done by mechanical control systems, namely by the governor system and vacuum system in the manifold [2].

At a certain throttle position, the engine will produce maximum power, when the spark advance in the optimal position, or what is known as Maximum Brake Torque (MBT) timing, or produce the maximum IMEP (Indicated Mean Effective Pressure). When the spark advance is less or greater, it will result in a decrease of power [3]. Furthermore, when the engine speed changes, the MBT timing also changes [4]. Basically, the greater spark advance, the greater power, but if it is too large, there will be knock, which will result in loss of power, wasted fuel, excess engine heat and the engine may quickly damaged [4]. Therefore the optimum ignition timing is the ignition timing when the sound of the knock is starting to be heard and then pushed back 2 CAD (crank angle degrees). This moment is the critical time margin to the MBT and this is called the knock-limited maximum brake torque (KL-MBT) [5]. This means that at the same time one can avoid the knock happens.

A conventional mechanical control system for the spark advance control was not able to provide the MBT. For a conventional engine, which is still widely used, if the ignition system was replaced it would be very costly and difficult. So in this study, a new method which is more appropriate is proposed. It provides the spark advance correction for the existing system

Received February 24, 2015; Revised April 18, 2015; Accepted April 29, 2015

electronically by Fuzzy Logic Ignition Control (FLIC), a system that will control the ignition time to be optimal (KL-MBT).

The optimum ignition time is a unique characteristic of a gasoline engine, which takes the form of a 3D data map which is the location of the ignition timing (spark advance) on the vertical axis : high revolutions (engine speed), and throttle opening (load) on the two horizontal axis , such as shown in Figure 1.

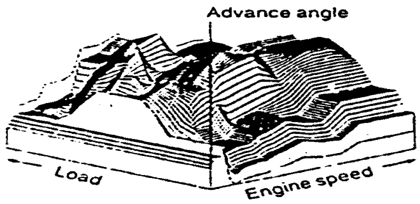


Figure 1. Characteristics of the 3D diagram of the spark advance [2]

In fact the characteristics of an engine in the 3D chart of spark advance are not linear and unique. Therefore, this FLIC control mechanism starts from reality to create the desired control and analysis of the system. The existing condition is used as an initial data to facilitate the analysis. Although the diagram is complex, not linear and the system analysis is very difficult, but the fuzzy logic can overcome of it.

The basic cofiguration of the fuzzy system [6] is to increase the fuzzyfier of the input, the fuzzy inference and the defuzzyfier of the output, where the real value of the fuzzifier transforms the input variables into fuzzy sets, while the defuzzyfier transforms the fuzzy set to a real value for the output variable. Fuzzy inference is used to process the input data to produce the right decisions based on the output of the basis of the fuzzy setting (fuzzy rule base) given.

In the application of the control, the fuzzy logic system was presented in Figure 2, which shows the architecture of the fuzzy controller that connects together the input, the process and the output.

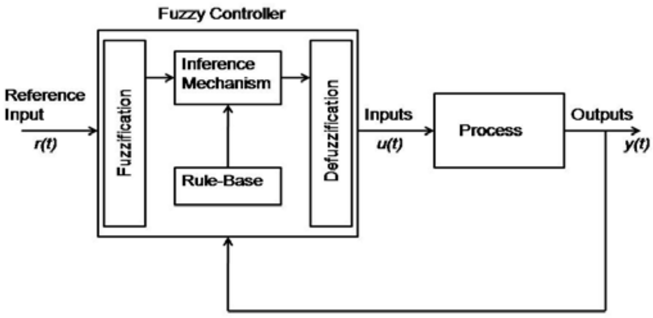


Figure 2. Fuzzy controller architecture [7]

The uses of the FLC (Fuzzy Logic Control) method which already exist are: for setting the hydrogen injection for diesel motor [8]; Method for optimum valve opening has also used FLC for fuel pump motor at a constant speed [9]; Fuel throttle settings. along with the ignition angle. are very effectively used to control the engine torque [10].

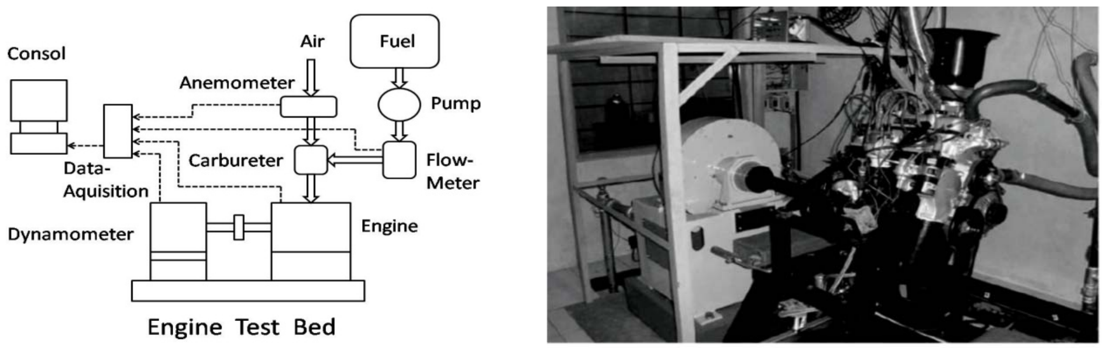
Other related studies include: A study of knocking on the fuel mix of gasoline with 10% ethanol having the best characteristics [11]; Using DMF mixture and spark timing optimization, increased efficiency, better exhaust emissions [12]. Optimization of spark timing and EGR (Exhaust Gas Recirculation), increase efficiency and reduce knock [13]; The new dynamic calculation method to calculate the threshold of the knock intensity, which is a complex and difficult thing when using the normal way [14]; Analysis of multidimensional simulations to reduce knock is by timing, EGR, the ratio of the mixture and the shape of the combustion chamber [15]; The computer models was used to predict the knock limited operating conditions

[16]; Knock detection method based on non-intrusive thermal signal transients on the cylinder wall was made [17]. Knock can be detected using an optical imaging technique based on the natural emission from the flame and UV spectroscopy. Radical classifications such as OH and HCO are detected and correlated with the onset and duration of the knock and the presence of hot-spots by the end-gas [18]. A study of knocking was done using LES (Large Eddy Simulation) coupled with detailed chemical kinetics [19]. A misfire (knock) has a unique pattern of vibration signals associated with a particular cylinder which can be extracted and analyzed to detect it by using a statistical approach and identify it by using decision tree algorithm [20]. When there is a knock, combustion that occurs will cause a rapid rise and fluctuate more strongly, so that the signal can be processed with a wavelet packet transformation to detect the knock [21]. Optimization of spark timing will give the maximum output power, high thermal efficiency, and restrict the occurrence of knock [22]. Setting the spark timing and the addition of CO and hydrogen gas will reduce the occurrence of knock [23]. Variations in the compression ratio done by varying the spark ignition timing gave these results: the higher compression ratio, the higher the indicated thermal efficiency, which leads to higher brake torque and lower break specific fuel consumption [24]. The calculated results demonstrated that the knock onset defined by pressure oscillations characteristics here was approximately consistent with that defined by heat release. The knock intensity, characterized by knock metrics, Maximum Amplitude of Pressure Oscillations (MAPO) and KI20 as the measure of the severity of knock [25].

So the purpose of this study is to create a new method to boost engine power and efficiency, by avoiding the knock occurs, by means of optimization of the spark advance based on the FLIC system that stores data in a 3D characteristics chart when the ignition timing of the engine is optimal, in order to make a correction to the conventional ignition, while eliminating the knock.

2. Research Method

This study was performed on a stationary engine mounted on an ETB (Engine Test Bed), in a laboratory, using a 1500 cc, 4-cylinder, 4 stroke engine with a carburettor and conventional ignition system. Figure 3 showed the installation of the engine, where it is equipped with a cooling system, temperature reader, dwell meter, flow meter, pressure gauges, vibration sensors, digital storage oscilloscope, interface and timing light (stroboscope). The measured data will be recorded on the computer through data acquisition.



(a) (b)

Figure 3. Engine Test Bed (ETB) System: (a) schematic (b) picture

The engine characteristics take the form of a data chart showing the optimum ignition timing (KI-MBT) which is done by running the engine with varied loads and revs, until detonation (knock) starts to occur. Then, at this point, data on engine speed, throttle openings and spark advance is measured as the maximum ignition timing (MBT) with the aid of a timing light (stroboscope). The revs are varied from 1,000 rpm to 3,000 rpm; the throttle is varied from 10% to 70%. The optimum ignition timing (KL-MBT) is the ignition timing at the start of detonation (knock) decreased by 2 CAD, whilst avoiding the conditions where a large detonation (knock) occurs.

A data chart of the optimal ignition timing (KL-MBT can be therefore prepared using the following steps. The first step in this study was (1) to set the time of combustion as the initial condition; then (2) open the throttle; and (3) select a particular engine speed and regulate the engine load; then (4) gradually changing the ignition timing until the detonation (knock) starts to be audible; then, when detonation is detected, (5) the firing time should be reduced slightly (2 CAD) to get the KL-MBT value; then (6) record the ignition timing (spark advance), throttle opening and engine speed. Next, repeat this procedure: change the throttle opening, then repeat steps 3, 4, 5, and 6. When all conditions are recorded, a 3D chart can be plotted. The characteristics of the engine are arranged in 2 conditions, namely: spark advance settings normal (conventional) or NBT (Normal Brake Torque) and optimum spark advance settings or KL-MBT (Maximum Brake Limited-Knock Toque). The difference between the two settings (KL-MBT vs. NBT) is the correction of the spark advance to make the engine produce maximum torque or maximum power at a certain engine speed and throttle opening, as shown in the Figure 4.

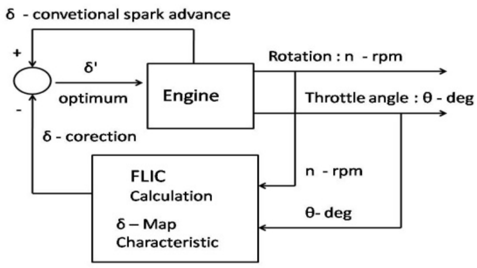


Figure 4. Conventional and FLIC system combination in knock correction

The control system will use a 3D chart, as a reference or corrections to the conventional system, see Figure 4. Whenever the driver of the car change the throttle opening for a few possible reasons, such as to speed up or slow down, the FLIC will set the ignition timing (spark advance) according to the 3-D chart. Corrections are made to change the conventional ignition timing in order to get the optimum ignition timing that gives the engine its best performance. The FLIC reads throttle opening and speed as input, and it therefore calculates the Fuzzy Inference to provide optimum ignition timing values.

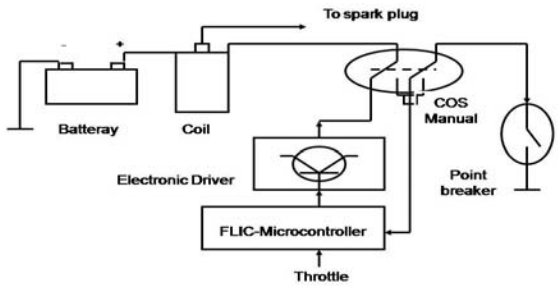


Figure 5. FLIC spark advance correction system

Figure 5 shows a schematic diagram of the installation of a fuzzy logic (FLIC) ignition control system for correction of the ignition timing. The micro controller does not directly activate the ignition coil, but does so through electronic drivers as the equipment interface. This circuit will keep the current microcontroller small enough so that it will be preserved and not quickly broken. The Change Over Switch (COS) is the transfer switch from the conventional ignition system to the FLIC system, in order to shift the system used at any given time.

3. Results and Analysis

The characteristics of the intensity of detonation (knock) generated using the eddy current dynamometer on the ETB, which measures the torque or power versus spark advance according to the engine speed variations, as shown in Figure 6, showed that: the power at a given speed of rotation (rpm) always increases with an increase in spark advance, but if the ignition timing is advanced again, detonation (knock) will arise and grow from small to very large.

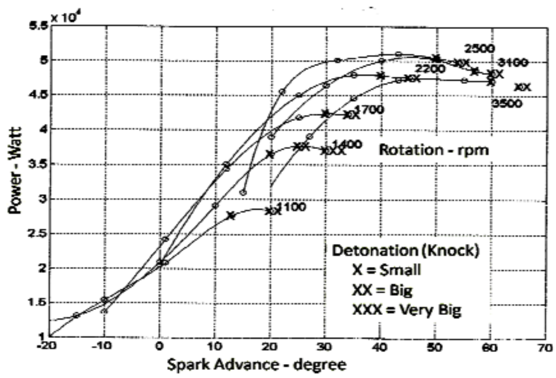
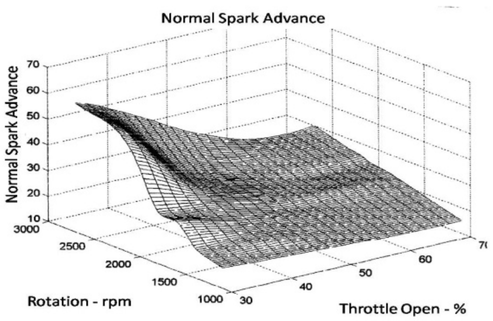
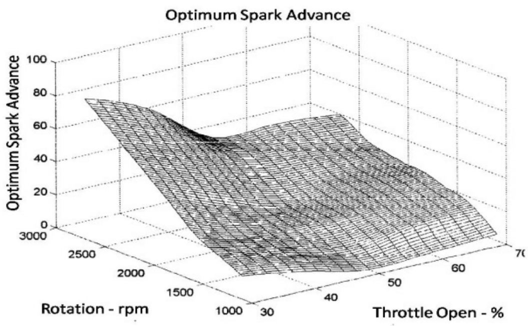


Figure 6. Engine characteristic in knock (detonation) vs. power and spark advance variation in the engine rotation

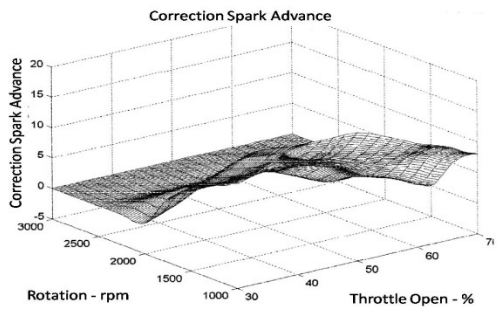
Furthermore, data from Figure 6 can be used to make: the characteristics of a normal spark advance which is a conventional spark advance with the normal default settings (NBT) as shown in Figure 7(a). The optimum spark advance (KL-MBT) is the MBT spark advance (when the engine reaches its maximum power) minus 2 CAD presented in Figure 7(b). Figure 7(c) is the calculation of the corrected spark advance which is the NBT spark advance reduced by the KL-MBT spark advance.



(a) Normal spark advance (NBT) conventional



(b) Optimum spark advance (Kl-MBT)



(c) The correction of spark advance (KL-MBT to NBT)

Figure 7. Spark advance characteristic: (a), (b), (c)

Figure 7(a) shows the characteristics of the engine at normal (conventional) ignition settings (NBT), indicating that the increase in spark advance occurs when there is an increase in the revs at a certain throttle opening, but if the throttle opening is increasied, then the spark advance declines. This indicates that the engine has a governor and a vacuum to control the size of thr spark advance. In a conventional ignition system, the governor is a mechanical system, which makes the increase in spark advance if the revs are increased. In the vacuum system, the pressure is measured at the intake manifold, which will make the decline of spark advance in case of a decrease in vacuum or throttle being opened wider.

The KL-MBT characteristic in Figure 7(b) is an optimal spark advance at which the engine can produce maximum power. Correction of the spark advance is a big difference from the value of NBT and the value of KL-MBT. This is a correction of a conventional spark advance (NBT) to KL-MBT spark advance so that the engine can operate in a condition of maximum power. The operating conditions of the KL-MBT spark advance means also avoiding the occurrence of the conditions where there is large detonation (knock).

The spark advance correction, in Figure 7(c), takes the form of data that can be turned into a chart. It is this correction value data chart that is processed by the FLC to give a decision on the value of the optimum spark advance, and it will be the basis for the FLC setting, as shown in Table 1.

Table 1. Rule table of the correction of the spark advance (δ - degree)

δ =

		Throttle opening (θ - %)				
		VS	**S**	**M**	**B**	**VB**
Engine speed (n - rpm)	**VB**	N	N	N	N	N
	B	N	N	VS	N	N
	M	N	VS	M	S	VS
	S	N	S	B	M	S
	VS	M	B	VB	B	M

VB = very big, B = big, M = medium, S = small, VS = very small, N = non (zero)

The Fuzzy membership function of each input and output variable is structured as follows: The fuzzy membership function of the open throttle carburettor (θ -%) is: VS = 30%, S = 40%, M = 50%, B = 60%, VB = 70 %. Fuzzy membership functions for engine rotation (n - rpm) is: VS = 1000rpm, 1500rpm = S, M = 2000rpm, B = 2500rpm, VB = 3000rpm. Fuzzy membership functions for spark advance (angle) is: VC = 0^o, VS = 4^0, S = 8^o, M = 12^0, B = 16^o, VB = 20^o, Calculations and decisions made using Fuzzy Logic Control are based on the membership functions and fuzzy rules table, as shown in Figure 8.

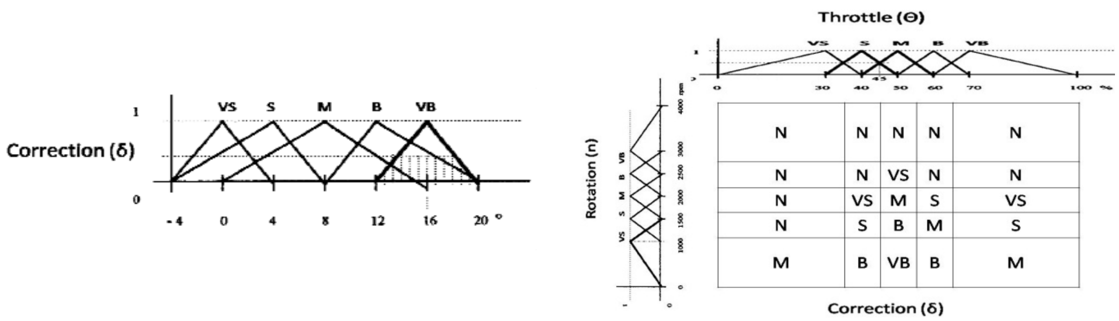


Figure 8. The combination of membership function with table rules of the FLIC

The result of the conventional ignition system combined with FLC for spark advance correction, from now on will be referred to as a FLIC combination system, and will certainly provide a new level of engine performance. The results are as follows:

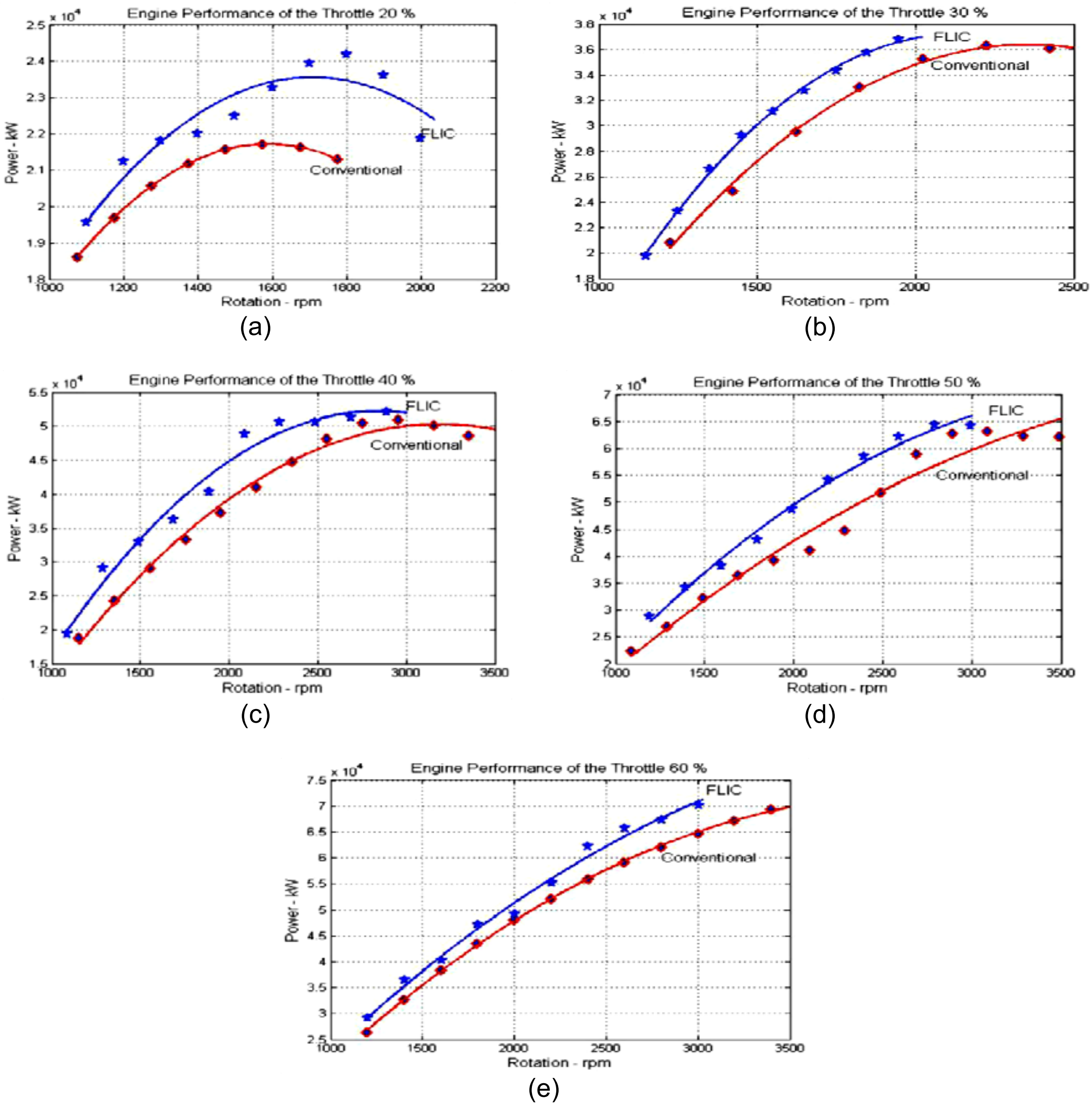


Figure 9. The comparison of the performance of FLIC vs. Conventional: with the throttle open: (a) 20%, (b) 30%, (c) 40%, (d) 50%, (e) 60%

In Figure 9 (a)-(e), with a throttle opening of 20% to 60%, is a picture of the engine performance in conventional conditions with normal spark advance settings as compared to the engine when equipped with the FLIC ignition system. It appears that the FLIC system gives about 15% greater power especially at high speed, which means that an engine with FLIC has better performance.

When the engine condition changes, it means that the FLIC, require manual adjustments. However, this controller is only suitable for the same or similar engines. For different engine, this controller should be adjusted to fit the characteristics of the proposed engine.

4. Conclusion

From this study it can be concluded that the combination of a conventional ignition system coupled with the spark advance correction, also known as the FLIC system, which is a combination of mechanical and electronic control systems, can provide the optimum ignition timing (KL-MBT) at any time and condition, thus increasing engine performance by about 15%

and at the same time it can avoid the knock (detonation), Hopefully future studies can be upgraded to a smarter system.

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