Mekanika: Majalah Ilmiah Mekanika

Experimental Test of Ignition Timing with Programmable CDI on Performance Single-Cylinder Otto Engine

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Abstract
Ignition timing is sparking from the spark plug based on the ignition angle during the compression stroke in the combustion chamber relative to the piston position and the crankshaft angular speed. Adjusting the ignition angle is one method to optimize the combustion process in the engine. An optimal combustion process can improve engine performance and reduce fuel consumption. This study investigates optimal data from ignition angle changes using a programmable Capacitive Discharge Ignition (CDI). The test was performed on a single-cylinder four-stroke Otto engine with standard ignition angle variations, +3°, +6°, and +9° before Top Dead Centre (TDC). The test results show that torque and power have increased while brake-specific fuel consumption has decreased. Optimal data acquisition at ignition angle of +9° with peak torque value of 6.91 Nm and peak power value of 4.80 kW, while the lowest value of specific fuel consumption is 0.234 kg/kWh, and the highest value of thermal efficiency is 36%. From this study, it was concluded that the ignition timing could affect the engine performance.

1 Introduction

The increasing demand for internal combustion engines, particularly Sparks Ignition (SI) engines, coupled with increasingly stringent emission regulations, has led to the development of more powerful, efficient, and cleaner SI engines. In the last decade, the SI engine has received many efforts to improve the combustion process, reduce fuel consumption, improve fuel formulation, and lower the emission of unwanted pollutants. The combustion process in an engine is characterized by the combustion duration, combustion perfection, and form factor. This process is strongly influenced by operating parameters such as compression ratio, engine speed, equivalence ratio, ignition timing, exhaust gas circulation, valve timing, combustion chamber design, and biogas composition [1]. Ignition timing is an important parameter that affects flame formation, the initial combustion process, and SI engine exhaust emission behavior [2]. An increase in cyclic variation in combustion is usually observed under idle, which will lead to adverse fluctuations in engine speed and output torque [3]. The coefficient of variation in the mean adequate pressure showed decreases with increasing load.

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As a significant technical parameter, Spark Timing (ST) is vital in improving fuel efficiency and reducing exhaust emissions [4]. If the spark occurs too quickly, the piston will be slowed in its upward motion. On the other hand, if the spark is delayed, the piston will move downwards, so in both cases, the work done on the piston will be reduced [5]. Capacitor-Discharge Ignition (CDI) for SI engines based on electronic ignition and contact point ignition consists of a pulse generation circuit, a pulse control circuit, the main charge and discharge of the coil capacitor, and a spark plug. Most SI machines use a high-voltage point contact system with the distributor to get the spark [6]. In another case, engines with sparks are expected to run with higher compression ratios and leaner air-to-fuel ratios to ensure increased combustion and fuel economy. When ignition timing is increased for leaner operation under conditions of increased cylinder descent, the gas flow in the spark plug gap increases significantly during spark discharge [7].

Sukarno et al. [8] researched the influence of changes in ignition timing using a programmable ECU applied to an automatic 115 cc motorcycle engine. The study tested engine performance in power, torque, and fuel consumption. They are testing a dynamometer on a motorcycle with five variations of ignition timing, namely standard ignition timing 15°, 17.5°, 20°, 22.5°, and 25° before TDC. The test results found that changes in ignition timing can increase engine performance and reduce fuel consumption. At standard ignition timing, the best ignition timing occurs at 17.50° before TDC, which produces a torque of 14.36 Nm, or an increase of 12.5% from the engine torque at standard ignition timing and an increase of 8.6 HP, or an increase of 13.9% from the engine power at standard ignition timing. The change in ignition timing to 17.5° before TDC also reduces fuel consumption to 0.1480 ml/s or a 28.95% decrease from fuel consumption at standard ignition timing [8].

The same study was also carried out by Healtanto et al. [9] using standard variations of ignition, ignition angle +2°, ignition angle +4°, ignition angle +6°, and ignition angle +8°. The study's results obtained an increase in thermal efficiency of 5.38%, an increase in torque of 0.773 Nm, an increase in power of 0.731 kW, an increase in Brake Mean Effectife Pressure (BMEP) of 66.149 kPa, and a decrease in Brake-Specific Fuel Consumption (BSFC) of 0.0057 kg/kWh. The study results show that using a new CDI with the correct ignition angle can increase combustion efficiency compared to a standard CDI [9]. Syahril Machmud et al. studied the effect of variations in the degree of ignition timing on fuel consumption in a 4-stroke gasoline engine with variations in engine speed (rpm) using premium fuel. This study used three variations of the degree of ignition timing: standard, advanced 3°, and advanced 6°. The results are the lowest fuel consumption (2,589 kg/hour), and the Specific Fuel Consumption (SFC) is generated by the ignition timing being advanced by 6° at a rotational speed of 9000 rpm [10].

The turbulence at greater rpm is sufficient to provide a suitable mixing of fuel and air, but much fuel is squandered since the ignition timing is not advanced because the pace of fire propagation stays constant [11-13]. Programmable CDI that can be reprogrammed injection time and duration, as well as ignition timing, to fit the demands of competitive or modified conventional engines. This mapping update is commonly referred to as re-mapping, and it alters the injection time and length, as well as the ignition timing, to maximize engine performance. One approach to increase motorbike performance is to change the ignition angle on the magnet in the bicycle ignition system motor [3,14,15].

2 Experimental Methods

The engine performance test (see Figure 1) is carried out with an instrument called the Dynojet 250i, an inertial dynamometer with eddy current load control. The primary material used in this study is programmable CDI to modify the standard ignition angle variations of +3°, +6°, and +9° before TDC. The equipment used in this research is vital to set, protractor, timing light, tachometer, laptop, stopwatch, buffet, dynamometer, and blower (test configuration is summarized in Table 1).

Figure 1. Testing on the dynamometer

Table 1. Ignition angle variation data

Engine Speed (rpm)	Variation of Ignition Angle Before TDC (º)			
	Standard	+3	+6	+9
2000	15	18	21	24
3000	23	26	29	32
4000	27.5	30.5	33.5	36.5
5000	29.5	32.5	35.5	38.5
6000	30	33	36	39
7000	30	33	36	39
8000	30	33	36	39
9000	30	33	36	39

Testing of torque, power, and fuel flow rate is carried out with the following steps:

1. Mount the motorcycle on the Dynojet 250i dynamometer tester and position the front wheels on the locking mounts and the rear wheels on the rollers.
2. Install the belt so that the motorcycle does not move during the test.
3. Install the engine speed indicator (rpm) on the coil cable.
4. Turn on the computer connected to the dynamometer.
5. Turn on the blower to cool the engine.
6. Turn on the engine at idle for approximately five minutes to get the optimal engine temperature.
7. Enter the transmission position in the third gear ratio.
8. Rotate the gas throttle to 3000 rpm and keep it constant, then increase the engine speed until it reaches full throttle. After that, the gas throttle is closed until the engine is idle.
9. On the computer screen, the results of the torque and power measurements will appear and then print out. Changes in engine speed from 4000 rpm to 9000 rpm with multiples of 1000 resulted from testing the programmable CDI ignition curve test data.
10. Repeat steps 7-9 with up to three tests.
11. Next, test the fuel flow rate by replacing the fuel tank with a burette and filling the buffet with fuel.
12. Enter the transmission position in the third gear ratio.
13. Rotate the gas throttle to 3000 rpm and keep it constant.
14. Use a stopwatch to calculate the time that can waste fuel by as much as 10 mL and record the measurement results.
15. Repeat steps 12-14 for an engine speed of 4000 rpm to 9000 rpm in multiples of 1000.
16. Turning off the motorcycle engine.
17. Turn off the dynamometer and lower the motorcycle.

2.1 Brake-specific fuel consumption

Specific fuel consumption is the amount of fuel used per power unit per operation hour. The following (Equations 1 and 2) can formulate specific fuel consumption

$$bsfc = \frac{\dot{m}_f}{Bp} \quad (1)$$

$$\dot{m}_f = \left(\frac{V}{t}\right) \times \rho \quad (2)$$

2.2 Brake thermal efficiency

Brake Thermal Efficiency (BTE) is a dimensionless measure of the thermal performance used by the engine by the total units of heat in the fuel consumed. The following (Equation 3) can make thermal efficiency calculations

$$\eta_{tb} = \frac{Bp}{\dot{m}_f \, Q_{hv} \, \eta_c} \quad (3)$$

3 Results and Discussion

3.1 Torque analysis

Based on the following data, it can be seen in Figure 2 that the effect of changes in the ignition angle on the torque value. The standard ignition angle has a peak torque of 6.41 Nm at 4000 rpm engine speed, the standard ignition angle +3° has a peak torque of 6.49 Nm at 6000 rpm engine speed, the standard ignition angle +6° has a peak torque of 6.68 Nm at 6000 rpm engine speed, and the standard ignition angle of +9° has a peak torque of 6.91 Nm at 6000 rpm engine speed. The use of a standard ignition angle of +3° experienced a decrease in torque of 0.15 Nm at 4000 rpm compared to the use of a standard ignition angle. However, in the 5000 rpm to 9000 rpm engine speed range, the torque increases sequentially by 0.09, 0.32, 0.34, 0.20, and 0.03 Nm compared to the standard ignition angle. Using standard ignition angles of +6° and +9° has increased torque at an engine speed of 4000 rpm to 9000 rpm compared to standard ignition angles. At a standard ignition angle of +6°, the sequential torque increases are 0.05, 0.25, 0.52, 0.65, 0.65, and 0.57 Nm. Meanwhile, at a standard ignition angle of +9°, the sequential torque increases are 0.42, 0.61, 0.74, 1.01, 1.02, and 1.30 Nm.

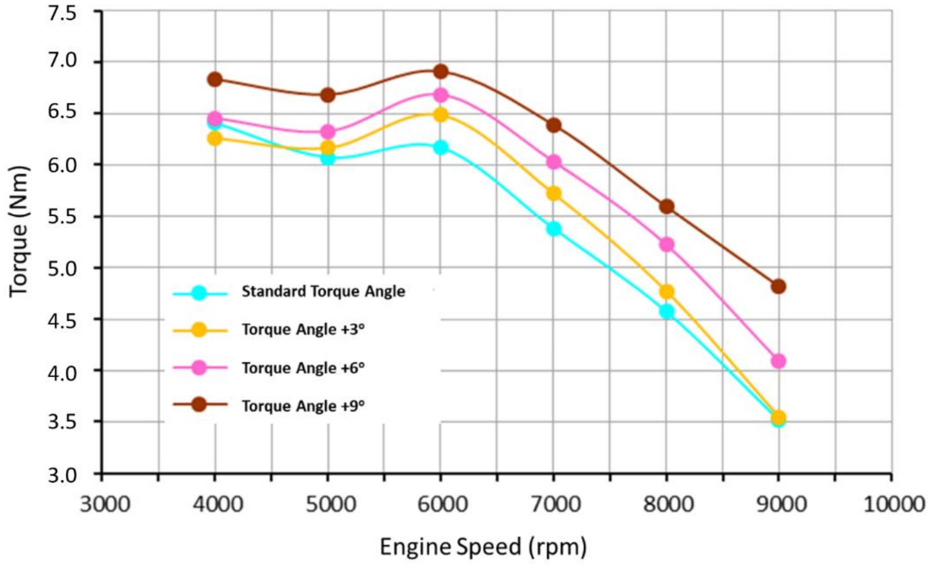

Figure 2. Torque and engine speed relationship graph

The fuel mixture is required to burn faster as the engine speed increases. This causes torque to drop as engine speed increases because the quicker the spin, the less time the fuel has to burn before reaching the upper dead point [5]. The quicker the engine rotates, the more the gasoline burns after the highest dead point. This is because combustion requires time [4].

3.2 Power analysis

Based on the following data in Figure 3, the effect of changes in the ignition angle can be seen on the power value. The standard ignition angle has a peak power of 3.98 kW at 7000 rpm engine speed, a standard ignition angle of +3° has a peak power of 4.19 kW at 7000 rpm engine speed, a standard ignition angle of +6° has a peak power of 4.43 kW at 7000 rpm engine speed, and a standard ignition angle of +9° has a peak power of 4.80 kW at 8000 rpm engine speed. Using a standard ignition angle of +3° experienced a power reduction of 0.07 kW at 4000 rpm compared to a standard ignition angle. However, in the engine speed range of 5000 rpm to 9000 rpm, there is a sequential power increase of 0.03, 0.19, 0.21, 0.18, and 0.03 kW compared to the use of standard ignition angles. Using standard ignition angles of +6° and standard +9° has increased power at engine speeds of 4000 rpm to 9000 rpm compared to standard ignition angles. At a standard ignition angle of +6°, the power increases are 0.04, 0.14, 0.35, 0.45, 0.57, and 0.53 kW, respectively. Meanwhile, at a standard ignition angle of +9°, the sequential power increases are 0.18, 0.33, 0.45, 0.80, 0.99, and 1.02 kW.

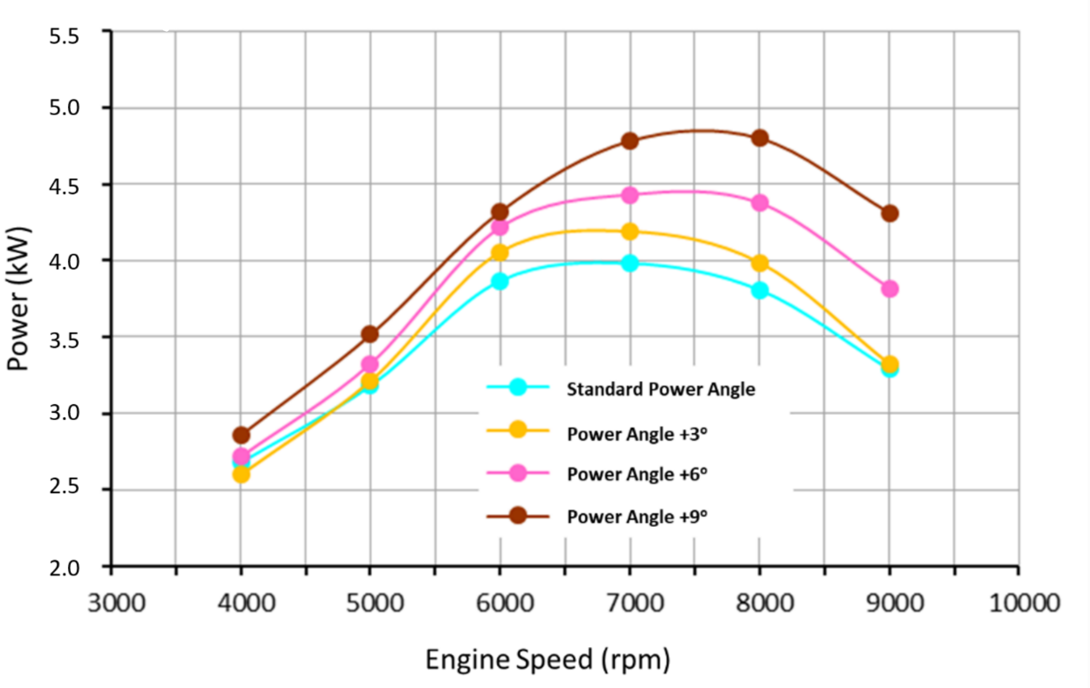

Figure 3. Power and engine speed relationship graph

The fuel mixture must burn entirely faster as the engine speed increases. Because the rotation is faster, the gasoline does not have time to burn entirely before the top dead point, resulting in a drop in power and an increase in engine speed [11]. The quicker the engine rotates; the more gasoline burns after the top dead point. This is because combustion takes time [5,16].

3.4 Brake-specific fuel consumption and thermal efficiency analyses

Based on data in Figure 4, it can be seen the effect of changes in the ignition angle on the BSFC value. The use of variations in the ignition angle of +3°, +6°, and +9° has decreased the value of specific fuel consumption at an engine speed of 4000 rpm to 9000 rpm from the standard ignition angle. Specific fuel consumption decreases sequentially by 0.003, 0.02, 0.025, 0.023, 0.028, and 0.033 kg/kW.h when an ignition angle of +3° is used. Then, at an ignition angle of +6°, the specific fuel consumption decreases sequentially by 0.016, 0.015, 0.033, 0.037, 0.062, and 0.116 kg/kW.h. Then, at the use of an ignition angle of +9°, the specific fuel consumption decreases sequentially by 0.040, 0.045, 0.059, 0.070, 0.090, and 0.162 kg/h. Also in Figure 5, the effect of changes in the ignition angle on the BTE value can be seen.

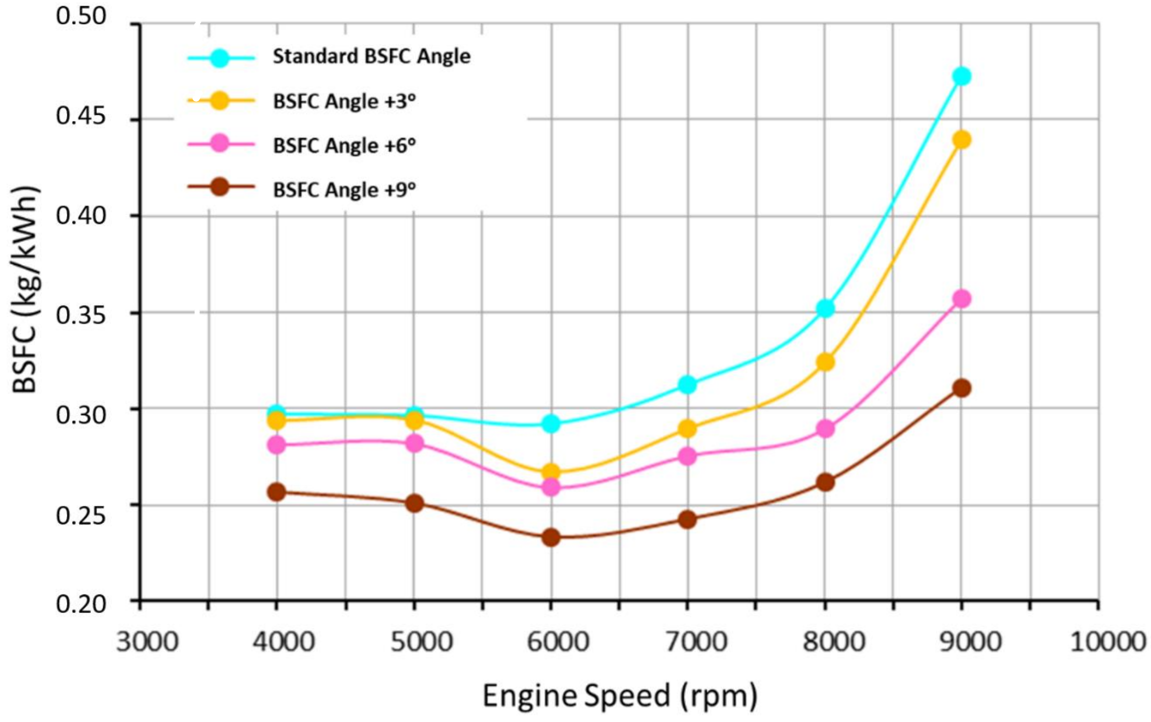

Figure 4. BSFC and engine speed relationship graph

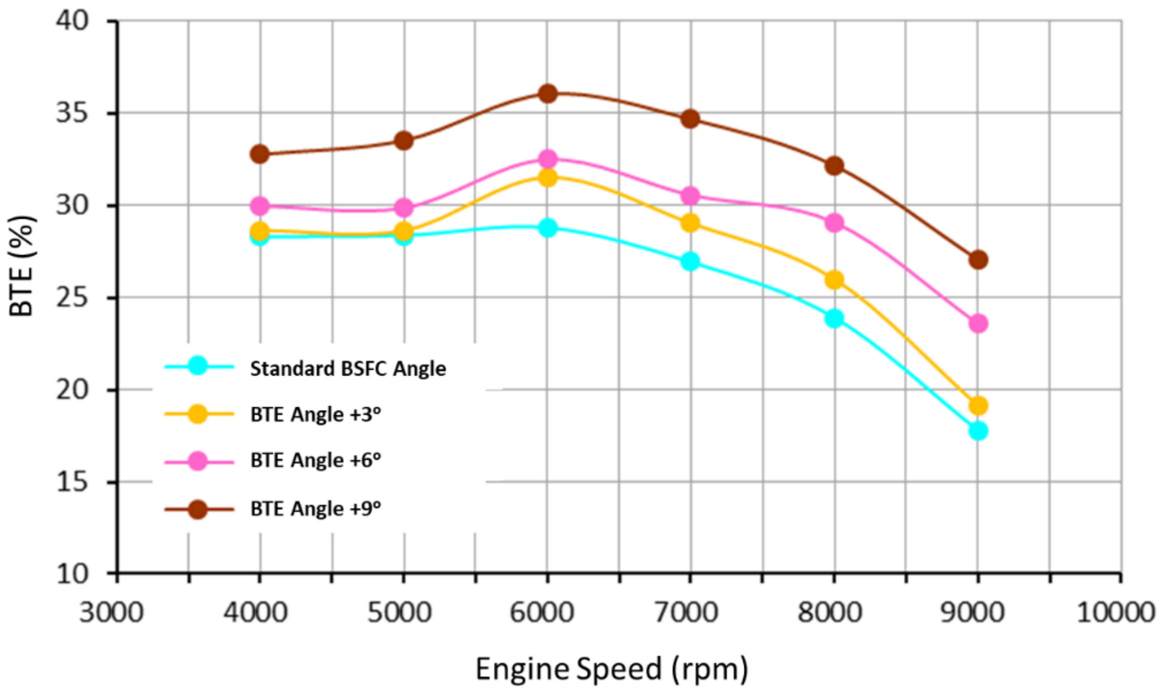

Figure 5. BTE and engine speed relationship graph

The use of variations in the ignition angle of +3°, +6°, and +9° has increased the thermal efficiency value at an engine speed of 4000 rpm to 9000 rpm from the standard ignition angle. With an ignition angle of +3°, the thermal efficiency increases sequentially by 0.34, 0.26, 2.72, 2.11, 2.08, and 1.35%. Then, using an ignition angle of +6° increases the thermal efficiency sequentially by 1.65, 1.49, 3.69, 5.16, and 5.78%. Then, using an ignition angle of +9° increases the thermal efficiency sequentially by 4.46, 5.15, 7.24, 7.74, 8.24, and 9.26%.

4 Conclusions

The following conclusions may be taken from the test data and performance analysis of the Otto four-stroke single-cylinder engine with variable ignition, utilizing a programmed CDI to produce particular torque, power, and fuel consumption values: High CDI may be used to program variations in ignition timing. Together with conventional combustion angles, improved torque, thermal efficiency, and specific fuel consumption significantly impact engine performance; of all variants, an ignition angle of +9° produced the best test results. Peak torque is 6.91 Nm at 6,000 rpm, peak power is 4.80 kW at 8,000 rpm, and the minimum specific fuel consumption is 0.234 kg/kWh at 6,000 rpm. At 6000 rpm engine speed, thermal efficiency is 36.04 %.

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