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Optimizing Ignition Timing for Gasoline Engines: A Study on Performance and Emissions

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Abstract
Multiple factors affect the performance of spark ignition (SI) engines, with ignition time being a crucial element. Accurate ignition timing is essential for optimizing engine performance and regulating exhaust emissions. This study examines the performance, fuel efficiency, and exhaust emissions of a 125cc engine by evaluating ignition timing variations at 55^0, 60^0, and 65^0 CA BTDC. The study involved direct evaluation of engine performance with a dynamometer test for torque and power, assessment of fuel consumption using a measuring cup, and investigation of exhaust emissions using a gas analyzer. The precise calibration of ignition timing discrepancies was accomplished via a motorbike diagnostic tool. The findings demonstrate that a 600 CA BTDC ignition timing variation produces excellent engine performance and efficient exhaust emissions. Optimal ignition timing profoundly influences engine performance and emission quality, rendering it essential for enhancing efficiency and mitigating environmental effects. Consequently, the results of this study may serve as a reference for practical applications in the field.

Keywords: ignition timing, engine performance, emission, fuel consumption.

1. Introduction

Fossil fuels, including gasoline and diesel, have historically been the cornerstone of transportation and worldwide energy generation[1][2][3]. The globe has faced significant energy crises resulting from the exhaustion of non-renewable fossil fuel reserves and escalating environmental issues[4]. Road cars, predominantly fueled by fossil fuel combustion, account for approximately 16% of worldwide carbon dioxide emissions[5]. Fossil fuel burning is a principal source of atmospheric pollutants, such as carbon dioxide (CO_2), nitrogen oxides (NO_x), and particulate matter, which substantially contribute to air pollution and climate change[6][7][8]. Gas fuels are anticipated to eclipse liquid fuels as the preferable energy source in the future, propelled by increasing apprehensions regarding climate change and the imperative for sustainability [9][10].

Although electric vehicles have experienced rapid development, passenger vehicles still primarily use Gasoline Direct Injection (GDI) engines with Spark Ignition (SI) as the main power source due to their favorable performance in terms of power output, fuel efficiency, and gas emissions[11]. However, GDI engines have higher particulate emissions compared to port fuel injection, especially when operating in stratified combustion mode, which reflects their economic advantages but results in more particle emissions due to incomplete combustion [12][13].

Numerous parameters influence the efficacy of SI engines, with ignition timing being a significant determinant. Ignition timing in SI engines pertains to the timing of the electrical spark used to ignite the air-fuel combination within the combustion chamber[14]. Accurate ignition timing is essential for enhancing performance and regulating engine emissions. Optimizing spark timing enhances efficiency and decreases emissions, allowing SI engines to comply with forthcoming pollution regulations[15].

Ignition timing is a vital factor in attaining optimal engine performance. The ideal configuration for efficiency is referred to as MBT, which denotes either minimum advance for optimal torque or maximum brake torque. Ignition timing is a critical element for combustion in gas-fueled spark-ignition engines [16]. Ignition time is a crucial determinant of engine performance and emissions; advanced ignition timing influences the engine's anti-knock characteristics, while retarded ignition timing impacts engine efficiency and fuel consumption [17].

Researchers have utilized diverse methodologies to attain optimal performance in SI engines. Ji et al.[18] identified variations with further retardation between 24° and 32° CA BTDC for excess air ratios of 1.2 and 1.4, respectively. The findings demonstrated that pure gasoline displayed a superior IMEP relative to hydrogen-gasoline mixes. Elsemary et al.[19] investigated the influence of spark timing on small spark-ignition engines utilizing hydrogen-gasoline blends with hydrogen volume fractions of 0%, 24%, 28%, 29%, 31%, and 49%. The study indicated that at 300 BTDC, fuel usage decreased by 31%. Shi et al.[20] proposed modifying the ignition timing of a hydrogen-gasoline engine from 40 to 160 CA BTDC in 30 CA increments to examine the impact of ignition timing on combustion and emissions. The findings indicated that augmenting the ignition timing enhanced fuel economy and diminished emissions. Yu et al.[21] examined the influence of ignition timing on hydrogen supplementation in spark-ignition engines by suggesting a modification of ignition timing from 10° to 30° CA BTDC and analyzing variations in injection timing at 75°, 90°, 105°, 120°, and 135° CA BTDC. The findings indicated that varying hydrogen ignition timings were ideal at an injection pressure of 4 MPa. The test outcomes for a combination of injection timing at 105° CA BTDC and ignition timing at 20° CA BTDC were deemed adequate, yielding a 4.5% enhancement in effective thermal efficiency. Prior research has concentrated on the influence of ignition timing on the performance and emissions of gasoline engines, analyzing factors such as ignition timing, injection timing, and fuel compositions. This study seeks to examine the impact of ignition timing by delineating changes at 55°, 60°, and 65° CA BTDC.

2. Methodology

Figure 1 shows the testing configuration for the data collecting procedure, establishing a thorough testing arrangement to document essential characteristics like engine performance (torque and power), fuel consumption, and exhaust gas emissions (CO, CO_2, HC, and O_2). A sophisticated dynamometer is employed to assess engine performance, with the motorcycle placed on a testing stand to guarantee precise and consistent data. To assess the composition of exhaust gas emissions, a gas analyzer equipped with strategically positioned sensors in the exhaust pipe is utilized. This apparatus facilitates the meticulous recording of emission data, offering a transparent assessment of the environmental consequences of the evaluated engine. A measuring cup is incorporated into the fuel system to assess fuel use. This test was conducted by analyzing the effect of varying ignition timing at 55°, 60°, and 65° CA BTDC on a 125cc engine, the specifications of which can be seen in Table 1. To ensure the accuracy of ignition timing settings, we used a motorcycle scan tool that allows for precise and effective adjustments. With the help of this tool, we were able to characterize the effect of ignition timing on engine performance and exhaust gas emissions more accurately.

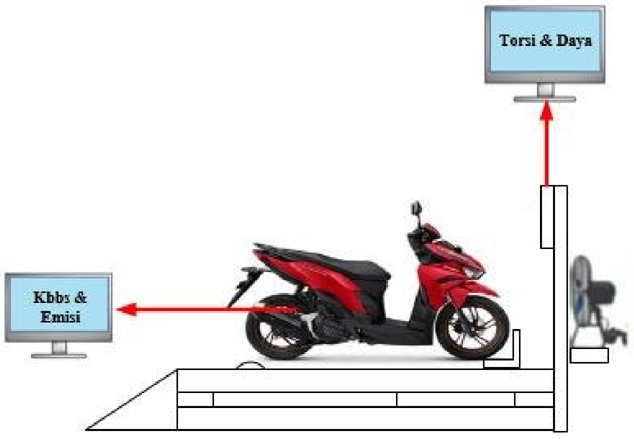


Figure 1. Setup Experimental

The testing procedure for data recording is as follows:

1. Test Preparation: Setting up the motorcycle on the dyno test and characterizing variations in ignition timing at 55°, 60°, and 65° CA BTDC.
2. Cooling Setup: Turning on the fan for engine cooling during testing.
3. Engine Activation: Starting the motorcycle engine and ensuring stable operational conditions.
4. Emission Measurement: Turning on the gas analyzer and placing the sensor into the exhaust pipe to measure exhaust gas emissions.
5. Performance Testing: Adjusting the speed controller on the motor to quickly increase engine speed, while the dyno test records torque and power parameters.
6. Test Repetition: Conducting the test repeatedly with variations in ignition timing at 55°, 60°, and 65° CA BTDC to ensure consistent results.
7. Data Collection: Collecting data in the engine speed range of 4500-7000 rpm to analyze engine performance and exhaust gas emissions.

Data Processing: Processing the data obtained from the test to analyze the effect of ignition timing variations on engine performance and exhaust gas emissions.

Table 1. Specifications of 125cc Motorcycle

Parameter	Specification
Engine Type	4-Stroke, SOHC, eSP, Liquid cooled
Fuel Supply System	PGM-FI (Programmed Fuel Injection)
Displacement	125cc
Bore x Stroke	52.4 x 57.9 mm
Compression Ratio	11.0 : 1
Transmissions Type	Automatic, V-matic
Maximum Power	8.2 kW (11.1 PS)
Maximum Torque	10.8 Nm (1.1 kgf.m)
Starter Type	Elektrik
Clutch Type	Automatic, Sentrifugal, Tipe Kering
Lubricant Oil Capacity	0.8 liter

3. Results and Discussion

This study analyzes the engine performance (torque and power), fuel consumption, and exhaust gas emissions (CO, CO_2, HC, O_2) on a 125cc engine by characterizing variations in ignition timing at 55°, 60°, and 65° CA BTDC.

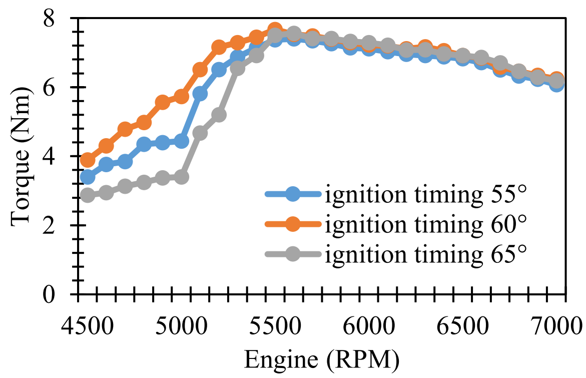


Figure 2. Engine Speed vs Torque

Torque. An analysis of engine performance depicted in Figure 2 shows that changes in ignition timing at 55°, 60°, and 65° CA BTDC significantly influence torque parameters, an essential measure for evaluating engine performance. The graph shows a significant increase in torque from 4500 rpm, reaching a maximum at 5500 rpm, with torque measurements of 7.37 Nm, 7.67 Nm, and 7.5 Nm linked to variations in ignition timing. This indicates that optimal ignition timing can significantly improve engine performance. The findings of this study demonstrate that ignition timing significantly affects engine performance. Specifically, advancing the spark ignition before top dead center enhances torque by promoting more efficient combustion processes, which in turn increases cylinder pressure and generates greater torque. The analysis of three ignition timing variations indicates that 60° CA BTDC yields the highest torque, outperforming both the 55° and 65° CA BTDC settings. This finding suggests that optimal ignition timing significantly improves engine performance.

Power. Evaluation of engine performance in Figure 3 shows that power parameters are significantly influenced by variations in ignition timing at 55°, 60°, and 65° CA BTDC. A significant increase in power is seen in the range of 4500 to 6300 rpm, with peak power values of 5.53 kW, 5.71 kW, and 5.64 kW for each ignition timing variation. These results show that optimizing ignition timing can significantly improve engine performance, as more efficient and effective combustion can increase cylinder pressure and produce greater power. This study also shows that earlier ignition timing before top dead center has a positive impact on engine power. This advantage is because the earlier combustion process allows the air-fuel mixture to burn more completely, resulting in greater cylinder pressure and higher power. Among the three ignition timing variations tested, 60° CA BTDC shows the best performance with the highest power, outperforming the 55° and 65° CA BTDC ignition timing variations.

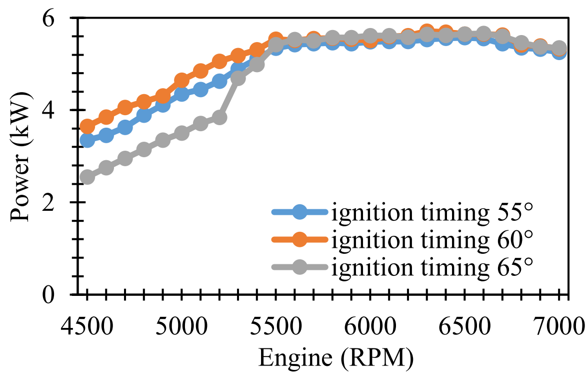


Figure 3. Engine Speed vs Power

Fuel Consumption. Figure 4 shows that variations in ignition timing affect engine fuel consumption. The graph indicates a decline in fuel consumption from 4500 rpm to 5500 rpm, followed by an increase up to 7000 rpm. This study's results demonstrate that the 55° CA BTDC ignition timing variation exhibits more efficient fuel consumption than the 60° and 65° CA BTDC ignition timing variations. This effect occurs because the spark ignition is excessively rapid, leading to an increased amount of fuel entering the combustion chamber. This study demonstrates that optimizing ignition timing is essential for enhancing fuel efficiency and minimizing excessive fuel consumption.

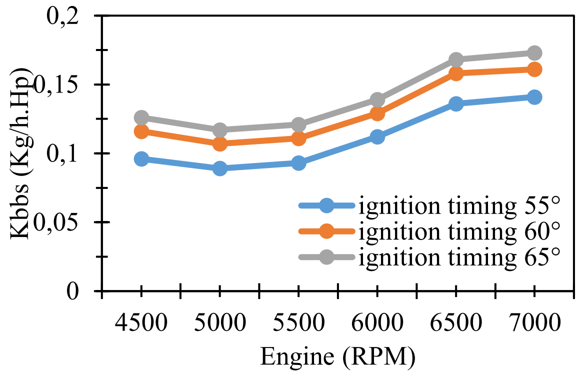
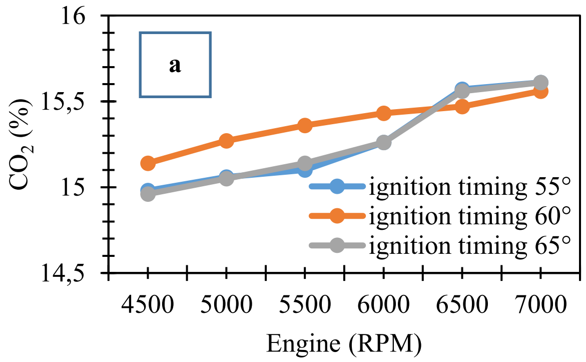
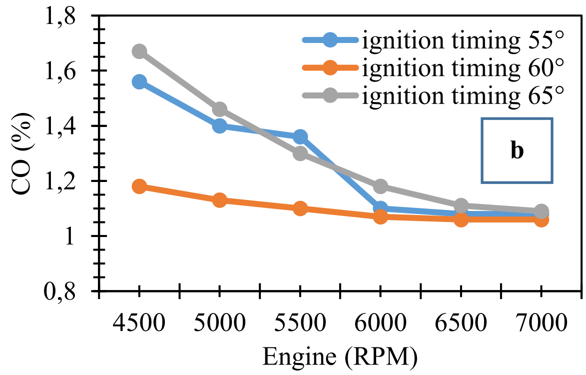


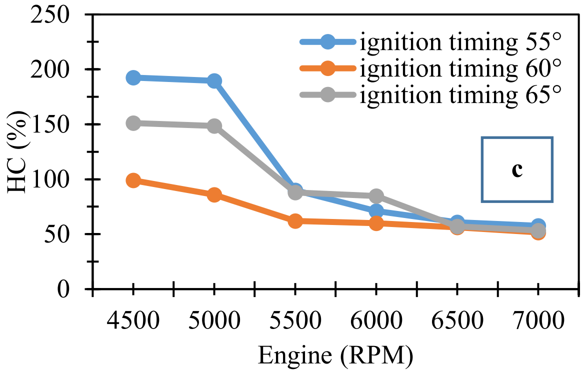
Figure 4. Engine Speed vs Fuel Consumption

Emissions. Figure 5(a) shows the results of CO_2 exhaust gas emission measurements for various ignition timing variations. The graph shows a significant increasing trend in CO_2 emissions as engine speed increases from 4500 rpm to 7000 rpm. The study results show that the 60° CA BTDC ignition timing variation has the lowest CO_2 emissions compared to the 55° and 65° CA BTDC ignition timing variations, especially in the engine speed range of 6500-7000 rpm. This indicates that optimal ignition timing can reduce CO_2 emissions and improve engine efficiency. Figure 5(b) shows the results of CO exhaust gas emission measurements for ignition timing variations of 55°, 60°, and 65° CA BTDC. The graph shows a significant decrease in CO emissions as engine speed increases from 4500 rpm to 7000 rpm. The study results indicate that the 60° CA BTDC ignition timing variation has the lowest CO emissions compared to other variations. This indicates that optimizing ignition timing can effectively reduce CO exhaust emissions. Figure 5(c) shows the results of HC exhaust gas emission measurements for all ignition timing variations. The graph shows a significant decreasing trend in HC emissions as engine speed increases. The 60° CA BTDC ignition timing variation proves to have the lowest HC emissions compared to other variations. This study's results indicate that optimizing ignition timing can significantly affect

HC exhaust emissions, thereby improving engine efficiency and reducing negative environmental impacts. Figure 5(d) shows the results of O_2 emissions measured from exhaust gas across different ignition timing variations. The graph illustrates a reduction in O_2 emissions with an increase in engine speed from 4500 rpm to 7000 rpm. The study results demonstrate inconsistency in O_2 emission outcomes across all variations of ignition timing. At 55° CA BTDC ignition timing, the 5000-5500 rpm range yields the highest O_2 emissions relative to other timing variations. At 60° CA BTDC ignition timing, the 6000-7000 rpm range exhibits the highest O_2 emissions. The findings of this study indicate that optimizing ignition timing variation, specifically at 60° CA BTDC, can positively influence environmental outcomes by generating O_2 gas at elevated engine speeds. Many factors influence exhaust gas emission results, including spark ignition occurring before top dead center, which may lead to incomplete combustion. This study demonstrates that optimizing ignition timing requires consideration of multiple factors to attain optimal and environmentally sustainable outcomes.







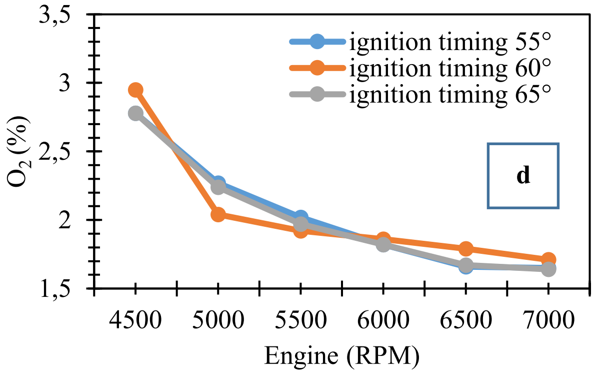


Figure 5. (a) CO_2; (b) CO; (c) HC; (d) O_2

4. Conclusion

This research examines the performance of a 125cc engine via direct experimentation. Engine performance parameters, including torque, power, fuel consumption, and exhaust gas emissions (CO_2, CO, HC, O_2), were analyzed with respect to varying ignition timing at 55°, 60°, and 65° CA BTDC. The findings demonstrate that the 60° CA BTDC ignition timing variation yields the highest engine performance in terms of torque and power relative to other timings. It yields superior results for all exhaust gas emission components (CO_2, CO, HC, and O_2) in comparison to other variations. In terms of fuel consumption, the 60° CA BTDC ignition timing variation exhibits the highest consumption relative to the 55° CA BTDC variation, while demonstrating lower consumption compared to the 65° CA BTDC variation. The findings suggest that a 60° CA BTDC ignition timing variation is optimal for enhancing engine performance and minimizing exhaust gas emissions. This work serves as a reference and can be directly applied in practical fields.

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