



Influence of rotor magnet geometry variation on performance characteristics of a fuel-injected four-stroke motorcycle engine using high-ethanol fuel blends

Wawan Purwanto^{1,2*}, Dwi Sudarno Putra^{1,2}, Ahmad Arif^{1,2}, Ihsan Nasution¹, Riko Saputra^{1,2,3}, and Samsul Arifin¹

¹ Departmen of Automotive Engineering, Universitas Negeri Padang, Padang, Indonesia

² Pusat Riset Mobil Hemat Energi (PRIME), Padang, Indonesia

³ Master's Program in the Departemen of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang, Padang, Indonesia

*Corresponding author email: wawan5527@ft.unp.ac.id

Abstract

The effect of varying the rotor magnet trigger geometry on the performance characteristics of a fuel-injected four-stroke motorcycle engine is studied, focusing on the applicability of high-ethanol fuel blends for renewable energy alternatives. The following three rotor configurations were applied: a standard rotor, a rotor with an extended trigger segment (+2 mm), and one with a shortened segment (-2 mm). Performance tests using a chassis dynamometer and exhaust gas analyzer recorded torque, power output, and emission profiles under various mixtures of Peralite–Pertamax–Ethanol up to 70%. It was observed that an extended rotor trigger segment can improve the response of ignition timing for more complete combustion. The maximum performance was obtained while operating on a mixture of 30:70 Pertamax–Ethanol, at a maximum torque of 8.15 N.m and 5.9 kW power. Ethanol-blended fuels proved to reduce emissions of hydrocarbon and carbon monoxide, pointing towards their role in promoting cleaner combustion and sustainable transportation energy transition.

Keywords

Ignition timing, Rotor magnet modification, Bioethanol fuel blends, Engine performance, Exhaust emissions

Introduction

The increasing demand for sustainable transportation energy has intensified research into renewable fuel utilization and ignition system optimization in small spark-ignition (SI) engines. Motorcycles, particularly in developing countries, remain dominant modes of transportation and contribute significantly to fuel consumption and urban emissions.

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Consequently, improving combustion efficiency while enabling the use of renewable fuels such as ethanol blends has become a critical research focus [1], [2]. High-ethanol fuels offer advantages in terms of higher octane number and oxygen content; however, their successful implementation requires precise ignition timing control to avoid combustion instability and performance degradation [3], [4].

In four-stroke SI engines, ignition timing plays a decisive role in determining combustion phasing, pressure development, and overall engine performance. For fuel-injected motorcycles that rely on crankshaft position signals, rotor magnet geometry directly influences the ignition trigger timing provided to the electronic control unit (ECU). Even small geometric variations in the trigger segment length can alter spark advance characteristics, affecting torque production, thermal efficiency, and exhaust emissions [5], [6]. Previous studies have shown that advancing ignition timing within an optimal window can enhance combustion completeness, especially when operating with high-octane or oxygenated fuels [7], [8].

Ethanol-blended fuels have been widely investigated as gasoline substitutes due to their renewable nature and favourable combustion properties. Ethanol exhibits a higher laminar flame speed and latent heat of vaporization compared to gasoline, which can promote more homogeneous charge formation and reduced knock tendency [9], [10]. However, excessive ethanol content may lead to slower flame initiation and misfire if ignition timing is not adequately adapted [11]. Several experimental studies on fuel-injected motorcycle engines have reported reductions in hydrocarbon (HC) and carbon monoxide (CO) emissions with increasing ethanol content, albeit often accompanied by trade-offs in torque and power output when ignition parameters remain unchanged [12], [13].

Recent Scopus-indexed studies have primarily focused on ECU remapping strategies, spark advance calibration, and injection duration optimization to improve engine performance under ethanol blending [14]–[16]. Other works have explored variable ignition timing control using programmable ECUs or sensor-based adaptive systems [17], [18]. Despite these advances, limited attention has been given to mechanical-based ignition trigger modification, particularly rotor magnet geometry variation, as a practical and low-cost approach for tuning ignition timing in fuel-injected motorcycle engines. Moreover, the combined effect of rotor geometry modification and high-ethanol fuel blends on engine performance and emission characteristics remains insufficiently explored.

Unlike previous studies that rely primarily on electronic recalibration, this study investigates the influence of rotor magnet trigger geometry variation as a mechanical ignition-tuning approach in a fuel-injected four-stroke motorcycle engine. By experimentally comparing a standard rotor with extended (+2 mm) and shortened (–2 mm) trigger segments under various Peralite–Pertamax–Ethanol fuel blends, this work provides new insights into ignition response behaviour and combustion performance. The findings contribute to the development of cost-effective ignition optimization

strategies that support high-ethanol fuel utilization without requiring complex ECU reprogramming, thereby offering practical relevance for sustainable motorcycle applications.

Therefore, this study aims to experimentally evaluate the effect of rotor magnet trigger geometry variation on torque, power output, and exhaust emissions of a fuel-injected four-stroke motorcycle engine operating with high-ethanol fuel blends. Chassis dynamometer testing and exhaust gas analysis are employed to quantify performance changes under different rotor configurations and fuel mixtures. The results are expected to clarify the interaction between mechanical ignition timing modification and ethanol-based combustion behaviour, supporting future development of renewable-fuel-compatible motorcycle engines.

Method

This study employed an experimental research design to evaluate the influence of rotor magnet trigger geometry variation on the performance and emission characteristics of a fuel-injected four-stroke motorcycle engine operating with high-ethanol fuel blends. An experimental approach was selected to allow direct manipulation of mechanical ignition parameters under controlled conditions, enabling a clear assessment of causal relationships between rotor geometry, ignition timing response, combustion behaviour, and engine performance.

The experimental object was a single-cylinder, four-stroke motorcycle engine (115 cc) equipped with an OEM electronic fuel injection (EFI) system. The EFI system comprised an electronic control unit (ECU), fuel injector and electric fuel pump, crankshaft position sensor (CKP), throttle position sensor (TPS), engine operating temperature (EOT) sensor, and a standard wiring harness. All EFI components were maintained in their original operational condition throughout the study to isolate the effects of rotor geometry and fuel composition.

To investigate the effect of ignition trigger geometry, three rotor magnet configurations were evaluated, as summarized in [Table 1](#).

Table 1. Rotor magnet geometry configurations and corresponding experimental response variables

Rotor configurations	Measuring results	Remark
X1	Y1	Standard rotor
X2	Y2	Extended trigger (+2 mm).
X3	Y3	Shortened trigger (-2 mm)

Each rotor was manufactured with controlled dimensional accuracy and installed sequentially on the same engine to ensure that performance variations were solely attributable to trigger geometry differences. The geometric layouts of the three configurations are illustrated in [Figure 1](#), highlighting the relative trigger segment positions that influence CKP signal detection and ECU ignition timing processing.

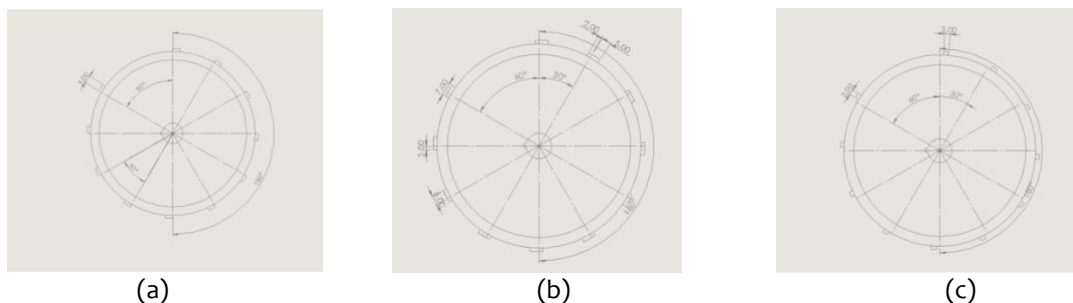


Figure 1. Geometric comparison of rotor magnet trigger configurations: (a) standard rotor, (b) extended trigger (+2 mm), and (c) shortened trigger (−2 mm).

To evaluate the interaction between ignition response and renewable fuels, the engine was tested using gasoline–ethanol blends consisting of Peralite, Pertamina, and bioethanol, with ethanol content varied up to 70% by volume. Fuel blends were prepared using volumetric measurement to ensure accuracy and repeatability. Prior to each test, the fuel system was flushed to prevent cross-contamination between different blends.

Engine performance testing was conducted using a chassis dynamometer to simulate real operating load conditions. Torque and power outputs were recorded across the engine speed range for each combination of rotor geometry and fuel blend. Each test condition was repeated three times, and average values were used for analysis.

Exhaust gas emissions were measured using a calibrated gas analyser. The measured parameters included carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO₂). Emission measurements were conducted at idle, medium, and high engine speeds after the engine reached steady-state operating temperature to minimize transient effects.

The experimental procedure followed a structured sequence: rotor installation, fuel blend preparation, engine warm-up, dynamometer testing, exhaust emission measurement, and data recording before system reset for subsequent tests. All experiments were performed under similar ambient conditions to minimize environmental influence.

Experimental data were analysed by comparing torque, power, and emission characteristics across rotor configurations and fuel blends. Performance trends were evaluated based on peak values, curve behaviour, and emission tendencies. Results are presented in tabular and graphical form to highlight the combined effects of rotor magnet geometry modification and ethanol blending.

The conceptual research framework of this study is presented in [Figure 2](#). The framework illustrates rotor magnet trigger geometry and ethanol fuel blend composition as independent variables influencing ignition timing response and combustion characteristics. These combustion-related effects subsequently determine engine performance outcomes, including torque, power output, and exhaust emissions. The framework emphasizes the interaction between mechanical ignition modification

and renewable fuel utilization as a pathway toward improved combustion efficiency and sustainable motorcycle engine operation.

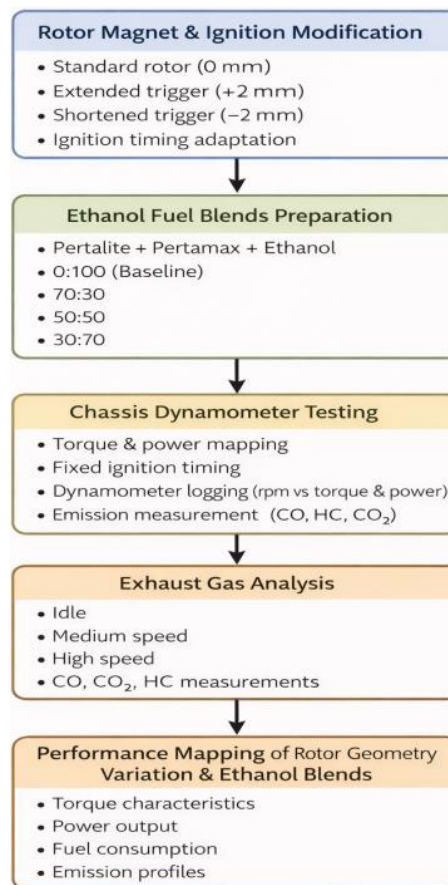


Figure 2. Research framework

Results and discussion

The influence of rotor magnet geometry on engine torque and power characteristics was evaluated by comparing the standard rotor configuration with the extended-trigger rotor (+2 mm) across various fuel types and ethanol blending ratios. The results obtained using the standard rotor configuration are summarized in [Table 2](#) and serve as the baseline for performance comparison.

For the baseline case using Peralite fuel, the standard rotor produced an average maximum torque of 8.20 N·m at 5510 rpm and a maximum power of 5.31 kW at 6670 rpm. These values represent the reference operating condition of the engine with factory ignition trigger geometry. When higher-octane fuels and ethanol blends were introduced, the standard rotor generally exhibited a reduction in torque and power, particularly at higher ethanol contents (60–70%). This behaviour reflects the limited adaptability of the standard ignition trigger to altered combustion characteristics associated with ethanol's lower heating value and different flame propagation behaviour.

A markedly different trend was observed when the rotor trigger segment was extended by +2 mm, as summarized in [Table 3](#). For Peralite fuel, the extended-trigger rotor

yielded an average maximum torque of 8.29 N·m at 6220 rpm and a maximum power of 5.78 kW at 6930 rpm, corresponding to increases of approximately 1.1% in torque and 8.9% in power compared with the standard rotor. This improvement indicates that advancing the effective ignition trigger enhances combustion phasing, allowing peak cylinder pressure to develop closer to the optimal crank angle region.

Table 2. Torque and power test results using standard rotor

Fuel Type	Avg. Engine Speed at Max Torque (rpm)	Avg. Max Torque (N·m)	Avg. Engine Speed at Max Power (rpm)	Avg. Max Power (kW)
Pertalite	5510	8.20	6670	5.31
Pertamax	5100	7.24	6240	4.36
Pertalite + 20% Ethanol	5440	7.21	6470	4.61
Pertalite + 30% Ethanol	5360	7.20	6050	4.59
Pertalite + 40% Ethanol	5530	7.22	6230	4.51
Pertamax + 50% Ethanol	5450	7.30	6170	4.51
Pertamax + 60% Ethanol	5880	7.08	6360	4.55
Pertamax + 70% Ethanol	5790	6.86	6080	4.54

Table 3. Torque and power test results using extended-trigger rotor (+2 mm)

Fuel Type	Avg. Engine Speed at Max Torque (rpm)	Avg. Max Torque (N·m)	Avg. Engine Speed at Max Power (rpm)	Avg. Max Power (kW)
Pertalite	6220	8.29	6930	5.78
Pertamax	6170	8.19	6960	5.72
Pertalite + 20% Ethanol	6110	8.22	6980	5.77
Pertalite + 30% Ethanol	6070	8.27	6980	5.81
Pertalite + 40% Ethanol	6360	8.24	6940	5.84
Pertamax + 50% Ethanol	6440	8.21	7560	5.84
Pertamax + 60% Ethanol	6530	8.22	7580	5.88
Pertamax + 70% Ethanol	6560	8.15	7070	5.90

Across all tested fuel types, the extended-trigger rotor consistently shifted both torque and power peaks toward higher engine speeds. This shift is particularly evident for ethanol-blended fuels, where peak torque values increased from the range of 6.86–7.30 N·m (standard rotor) to 8.15–8.29 N·m (extended rotor), while peak power increased from approximately 4.5–4.6 kW to nearly 5.8–5.9 kW. Such behavior confirms that ignition timing sensitivity becomes increasingly important at elevated engine speeds and under oxygenated fuel operation.

The interaction between rotor magnet geometry and ethanol fuel blending exhibits a clear synergistic effect on engine performance. Under the standard rotor configuration, increasing ethanol content generally led to a gradual decline in torque and power,

particularly at ethanol concentrations above 50%. This trend is primarily attributed to ethanol's lower heating value combined with ignition timing that is not sufficiently advanced to exploit ethanol's faster flame speed.

In contrast, the extended-trigger rotor significantly mitigated the performance penalty associated with high ethanol content. The most favourable operating condition was observed with a 30:70 Pertamina–Ethanol blend, where the engine achieved an average maximum torque of 8.15 N·m and a peak power of 5.90 kW. Compared with the same fuel blend under the standard rotor configuration, this represents a substantial improvement in both torque and power output.

These results confirm that modifying the rotor trigger geometry enhances ignition timing responsiveness, which is critical for high-ethanol fuel operation. Ethanol's higher octane rating and inherent oxygen content promote faster and more stable flame propagation, and when combined with optimized ignition phasing, result in improved combustion efficiency and power delivery.

Emission measurements further support the observed performance improvements. Across all tested fuel blends, the extended-trigger rotor consistently reduced carbon monoxide (CO) and hydrocarbon (HC) emissions compared with the standard rotor, while carbon dioxide (CO₂) concentrations increased. This emission pattern indicates more complete combustion, particularly at idle and medium engine speed conditions. Detailed emission data are presented in [Tables 4](#) and [5](#).

Table 4. Exhaust emission characteristics using standard rotor

Fuel Type	Engine Speed	CO (%)	CO ₂ (%)	HC (ppm)
Pertalite	Idle (1200 rpm)	1.61	3.87	92.67
	Medium (5000 rpm)	4.54	7.80	140.00
	High (8000 rpm)	4.45	5.70	255.33
Pertamax	Idle (1200 rpm)	3.15	5.00	316.00
	Medium (5000 rpm)	2.77	9.60	248.00
	High (8000 rpm)	6.34	8.80	399.00
Pertalite + 20% Ethanol	Idle	1.21	3.26	76.00
	Medium	3.66	5.73	137.67
	High	5.86	8.20	323.67
Pertalite + 30% Ethanol	Idle	1.47	6.13	116.33
	Medium	4.63	7.27	154.00
	High	5.13	8.33	266.67
Pertalite + 40% Ethanol	Idle	1.23	6.02	115.10
	Medium	5.84	7.52	120.12
	High	5.98	9.43	276.33
Pertamax + 50% Ethanol	Idle	1.49	6.06	337.67
	Medium	2.90	9.20	200.00
	High	3.50	9.30	307.00
Pertamax + 60% Ethanol	Idle	0.07	5.60	100.00
	Medium	0.24	8.80	475.00
	High	3.38	9.40	542.00
Pertamax + 70% Ethanol	Idle	0.11	6.20	88.00
	Medium	0.13	9.80	157.00
	High	1.76	10.90	288.00

Table 5. Exhaust Emission Characteristics Using Extended-Trigger Rotor (+2 mm)

Fuel Type	Engine Speed	CO (%)	CO ₂ (%)	HC (ppm)
Pertalite	Idle (1200 rpm)	2.80	3.80	254.00
	Medium (5000 rpm)	2.28	5.50	83.00
	High (8000 rpm)	4.27	6.50	323.00
Pertamax	Idle	2.37	4.30	144.00
	Medium	2.72	4.80	86.00
	High	3.03	6.50	153.00
Pertalite + 20% Ethanol	Idle	2.49	4.00	187.00
	Medium	2.78	4.50	89.00
	High	3.70	6.70	220.00
Pertalite + 30% Ethanol	Idle	2.70	4.20	208.00
	Medium	3.49	5.70	130.00
	High	3.77	6.70	193.00
Pertalite + 40% Ethanol	Idle	2.53	3.80	149.00
	Medium	1.99	5.80	85.00
	High	3.24	6.10	166.00
Pertamax + 50% Ethanol	Idle	0.32	5.10	60.00
	Medium	1.07	6.10	37.00
	High	1.70	7.30	146.00
Pertamax + 60% Ethanol	Idle	0.85	4.80	92.00
	Medium	0.51	6.00	70.00
	High	3.61	7.00	252.00
Pertamax + 70% Ethanol	Idle	0.47	4.70	81.00
	Medium	0.57	6.20	58.00
	High	1.02	6.60	156.00

Overall, the results demonstrate that rotor magnet geometry modification plays a critical role in maximizing the performance and emission benefits of high-ethanol fuel utilization in small-displacement, fuel-injected motorcycle engines.

The observed performance enhancement with the extended rotor trigger can be attributed to a more favourable ignition timing relative to piston position. By effectively advancing the ignition reference, the extended trigger promotes improved peak pressure development closer to top dead center, resulting in higher indicated work output and enhanced torque–power characteristics. Similar trends have been reported in studies investigating mechanical ignition trigger modifications, where optimized spark timing significantly influenced combustion phasing and engine efficiency [19].

When combined with ethanol-blended fuels, which possess higher octane ratings and inherent oxygen content, the optimized ignition response becomes increasingly critical. Ethanol alters flame propagation speed and combustion kinetics, requiring more precise ignition control to fully exploit its combustion potential. Recent studies on sustainable ignition strategies for ethanol-fuelled spark-ignition engines have emphasized that ignition optimization plays a decisive role in compensating for ethanol's lower energy density [20].

Although high ethanol content generally reduces the heating value of the fuel, the improved combustion efficiency achieved through the extended rotor configuration effectively compensates for this drawback. As a result, performance degradation at high ethanol blending ratios is significantly mitigated. These findings are consistent with

previous investigations highlighting the importance of ignition timing optimization in ethanol-fuelled SI engines [4], [16], [18]. Notably, the present study extends existing knowledge by demonstrating that a low-cost mechanical rotor modification can effectively complement ethanol fuel utilization without requiring complex ECU recalibration, offering a practical pathway toward sustainable performance enhancement in small-displacement motorcycle engines.

Conclusion

This study demonstrates that rotor magnet trigger geometry significantly influences ignition timing behaviour, engine performance, and emission characteristics in a fuel-injected four-stroke motorcycle engine operating on ethanol-blended fuels. The extended trigger rotor (+2 mm) consistently improved torque and power output, with the optimal performance achieved using a 30:70 Pertamina–Ethanol blend, producing 8.15 N·m torque and 5.9 kW power. Emission analysis confirmed substantial reductions in CO and HC alongside increased CO₂ levels, indicating more complete combustion. The findings establish that mechanical rotor geometry modification, when combined with high-ethanol fuels, provides an effective, low-cost alternative to ECU recalibration for optimizing ignition performance, supporting cleaner combustion and sustainable motorcycle engine applications.

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