Optimization of Injection and Ignition Timing using a Programmable ECU to Enhance Performance of a Four-Stroke Motorcycle Engine Implementation of Ethanol Gasoline Engine

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Abstract. The performance of four-stroke spark-ignition motorcycle engines is strongly influenced by the precision of fuel injection and ignition timing control. However, factory-set Engine Control Units (ECUs) generally apply fixed calibration maps that are not optimized for varying load and speed conditions, limiting combustion efficiency and output potential. This study investigates the optimization of injection timing and ignition timing using a programmable ECU to improve torque and power characteristics of a four-stroke motorcycle engine. Experimental testing was conducted by comparing baseline performance using the stock ECU configuration against multiple calibration variations executed through a BRT Juken 5 programmable ECU. Engine torque and power output were measured using a chassis dynamometer, while combustion behavior was analyzed through response trends across different engine speeds. The results indicate that advancing injection timing and ignition timing within a controlled range significantly improves combustion stability, leading to increased torque and power output, particularly at mid-to-high RPM ranges. The improvement is attributed to more effective air–fuel mixture preparation and more complete flame propagation during the power stroke. Conversely, excessive timing advance or retardation results in incomplete combustion or detonation tendencies, confirming the need for precise calibration boundaries. These findings demonstrate that programmable ECU-based tuning provides a practical and adaptive approach to enhancing engine performance without requiring mechanical modification, supporting the broader development of electronically optimized combustion systems in small-displacement motorcycles.

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1 Introduction

Progress in automotive technology has catalyzed numerous advancements in motor vehicle combustion systems, especially in motorbikes. An noteworthy innovation, as detailed in [1, 2], is the implementation of Electronic Fuel Injection (EFI), which is progressively supplanting traditional carburettor systems. The EFI system facilitates enhanced fuel supply regulation via the Electronic Control Unit (ECU), consequently augmenting combustion efficiency, engine performance, and diminishing exhaust pollutants. By employing diverse sensors, including the Throttle Position Sensor (TPS), Engine Oil Temperature (EOT), Oxygen Sensor (O_2), and Crankshaft Position Sensor (CKP), the ECU can ascertain the requisite fuel injection and ignition timing suitable for the engine's operational conditions. Nonetheless, in practice, numerous motorcycles continue to employ carburettor systems owing to economic considerations, maintenance simplicity, and entrenched engine design attributes.

The issue is that the manufacturer's default ECU settings are often calibrated for conventional operating conditions, which may not yield optimal engine performance across diverse usage scenarios. In certain instances [5-7], vehicle operators seek enhanced engine performance beyond conventional standards, such as for racing, harsh weather, or the optimization of specific engine attributes. Consequently, as indicated [8], altering the engine control system via ECU reprogramming or employing programmable ECUs has emerged as a prevalent method for manipulating combustion characteristics, including fuel injection quantity and ignition timing.

Efforts to improve engine performance have often been carried out through mechanical modifications such as bore-up, camshaft profile changes, or the use of piggyback ECUs [9]. However, these modifications have the potential to pose a risk to the long-term reliability of the engine due to significant mechanical structural changes. This approach often improves performance in the short term but can accelerate engine component wear. Therefore, a safer and more efficient approach to improving engine performance is needed, namely through the optimisation of electronic combustion control systems without making major mechanical changes to the engine.

Prior research has demonstrated that EFI systems can provide superior performance compared to carburetor systems. Research by [10, 11] indicated that at an engine speed of 3500 rpm, an engine equipped with an EFI system generated 44.179 kW of power, whilst an engine utilizing a carburettor system produced 43.154 kW of power, reflecting an increase of around 2.37%. The findings suggest that more accurate fuel injection settings can enhance combustion efficiency and engine performance. Nonetheless, the majority of these studies remain confined to a comparison of EFI and carburettor systems, neglecting a thorough investigation into the conversion process of carburettor engines to injection systems governed by programmable ECUs, as well as the impact of fuel injection parameter adjustments and ignition timing on engine performance attributes.

Based on these conditions, there is still a gap in research regarding how reconfiguring the combustion system through a programmable ECU in engines that originally used a carburettor system can affect engine performance, particularly in terms of torque and power parameters. Therefore, this study aims to analyse the effect of converting the fuel system from a carburettor to an injection system controlled by a programmable ECU in a

4-stroke motorcycle engine, as well as to evaluate the effect of fuel injection settings and ignition timing on engine performance characteristics. The results of this study are expected to contribute scientifically to the development of strategies for optimising combustion systems based on electronic control without requiring significant mechanical modifications to the engine.

2 Methods and materials

This research falls under the category of experiments. Finding the relationships between known variables and putting treatment-based hypotheses to the test are common goals of experimental research. A control group experimental model with a pretest-posttest protocol is used in this investigation. The purpose of this research is to find out how changing the injection and ignition timing on the Juken 5 BRT ECU of a Yamaha Vega ZR motorbike affects the bike's torque and power in a 4-stroke engine. **Fig.1** shows the treatment that was used in this investigation.

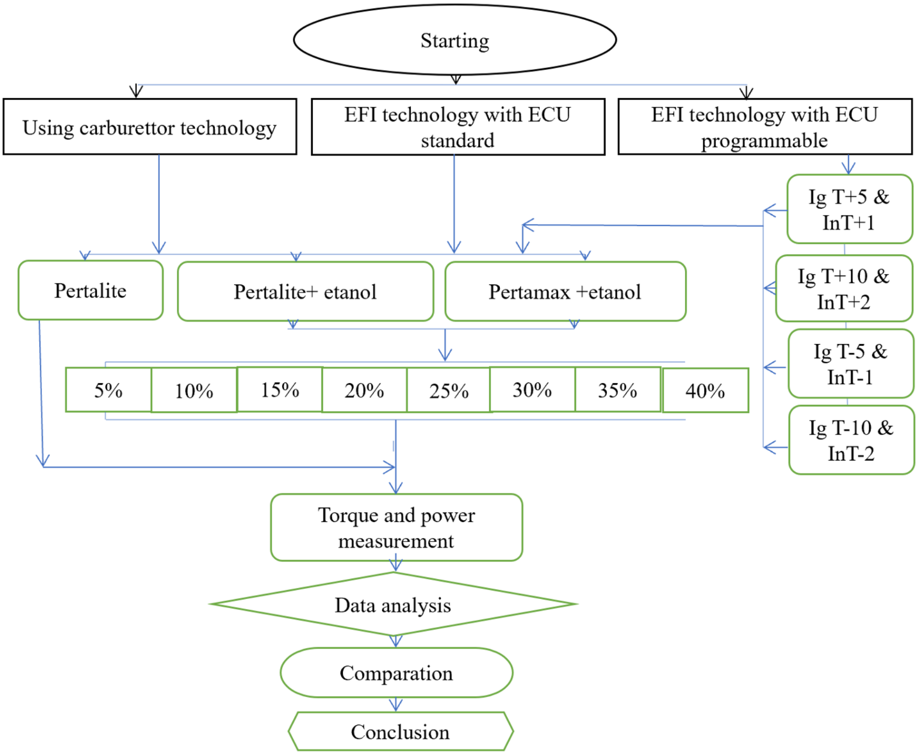
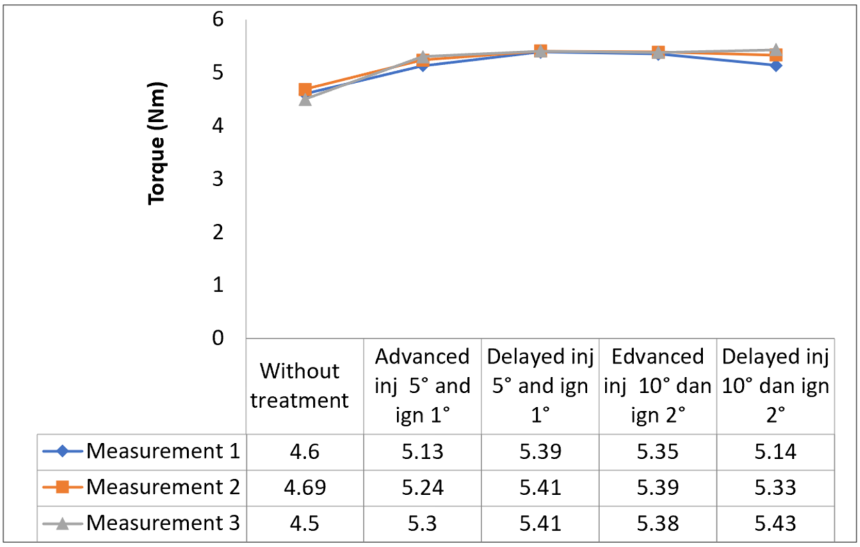


Fig. 1. Research flowchart

An air-cooled, 4-stroke, single-overhead cam (SOHC) engine with a 108.2 cc stroke volume, 50 mm diameter, and 55.1 mm stroke length was the research object in this study. The researchers of Padang State University's Department of Automotive Engineering were part of the engineering faculty. Using a dynamometer, the researcher in this study measured the engine measured power and torque. The treatments with programmable changes were the ones that were measured. A standard ECU was used to adjust the standard performance before measurements were taken, following the manufacturer's standards and without treatments or modifications. We timed each measurement so that we could achieve our maximum torque and power. The dynamometer was used to measure the power and torque of a 4-stroke engine, and the data was collected directly from a 4-stroke motorcycle. The data was placed into a table for processing after collection, and the outcome was a graph showing the tested engine's power and torque percentages.

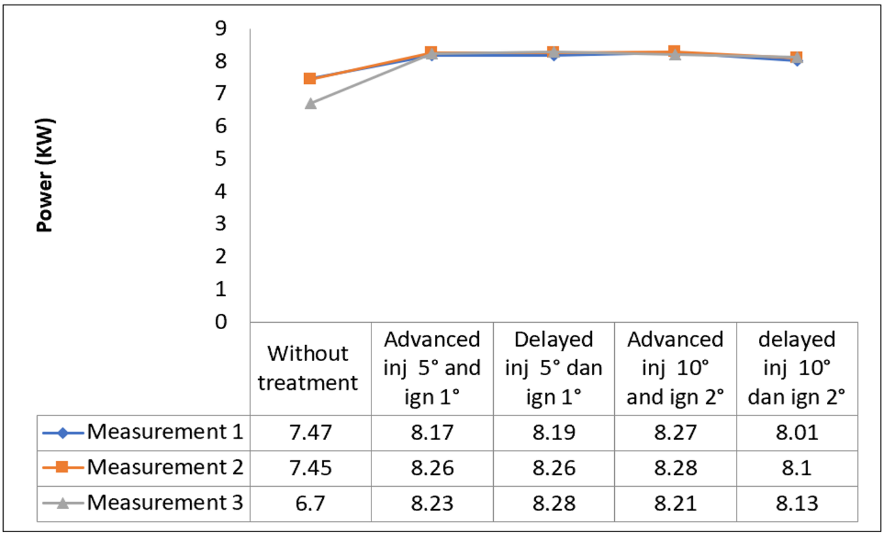
3 Results and discussion

Fig. 2 and 3 display the average power data derived from power tests conducted on a 4-stroke motorbike with the best ethanol-blended Pertalite fuel and a programmable electronic control unit (ECU). Figures 2 and 3 show that a programmable ECU produces more torque and power than a carburettor or a regular ECU. A 4-stroke engine's power and torque can be changed by using a carburettor, a regular electronic control unit (ECU), or a programmable ECU, as shown in the graph. The power test reveals discrepancies in performance across the carburettor, regular ECU, and programmable ECU. The power output drops from 5.54 kW when using the carburettor to 5.31 kW when using the basic ECU and 5.20 kW when using the programmable ECU. Next, the carburettor, regular ECU, and programmable ECU all show their differences in the torque test. Torque output from the carburettor is 8.76 N.m., but it drops to 8.2 N.m. in the test with the regular ECU and rises to 8.18 N.m. with the programmable ECU.



	Without treatment	Advanced inj 5° and ign 1°	Delayed inj 5° and ign 1°	Edvanced inj 10° dan ign 2°	Delayed inj 10° dan ign 2°
◆ Measurement 1	4.6	5.13	5.39	5.35	5.14
■ Measurement 2	4.69	5.24	5.41	5.39	5.33
▲ Measurement 3	4.5	5.3	5.41	5.38	5.43

Fig. 2. Torque characteristics



	Without treatment	Advanced inj 5° and ign 1°	Delayed inj 5° dan ign 1°	Advanced inj 10° and ign 2°	delayed inj 10° dan ign 2°
◆ Measurement 1	7.47	8.17	8.19	8.27	8.01
■ Measurement 2	7.45	8.26	8.26	8.28	8.1
▲ Measurement 3	6.7	8.23	8.28	8.21	8.13

Fig. 3. Power characteristics

Exhaust emission tests using the best Pertamax fuel and the best Pertalite fuel show considerable differences in power and torque, as seen in Figures 2 and 3. Utilising the optimal Pertamax ethanol fuel variation from exhaust emissions (60% ethanol) and the optimal Pertalite ethanol fuel variation from exhaust emissions (20% ethanol) impacts the power and torque generated by 4-stroke motorbikes, as seen by the graph. When comparing the best ethanol fuel variations from exhaust emissions, the Pertamax and Pertalite models show different performance at 20% and 60% ethanol, respectively, in the power test, this results as described [14-16]. The best Pertamax ethanol fuel variety (60%) reduced the power to 4.54 kW, whereas the best Pertalite ethanol (20%) resulted in 4.59 kW of power. The best Pertamax ethanol fuel variation from exhaust emissions (60% ethanol) and the best Pertalite ethanol fuel variation from exhaust emissions (20% ethanol) differ in the torque test. The torque measured 7.20 N.m. while using the best Pertamax ethanol fuel variation (60%) and the best Pertalite ethanol (20% ethanol), but it dropped to 6.86 N.m. when using the latter.

Fig. 2 and **Fig. 3** display the power and torque, respectively, and they demonstrate the variation in torque without treatment, after 50 inj 10, 100 inj 20, and 50 inj 10, 100 inj 20. The graph illustrates the effects on 4-stroke motorbike power and torque of varying injection timings and ignition timings in untreated tests, including 50 degrees ahead of the ignition and 10 degrees behind it, 100 degrees ahead of the ignition and 20 degrees behind it, and 50 degrees behind the ignition and 10 degrees behind it. The result of the power test conducted without treatment was 4.59 kW. The power test resulted in an increase of 5.22 kW when the injection was advanced by 50 degrees and the ignition by 10 degrees. There was an increase to 5.37 kW in the test using a 100-step injection advance and a 20-step ignition advance. There was a drop to 5.30 kW in the injection 100 ignition 20 test, but an increase to 5.40 kW in the power test with delayed injection 50/10. Distinctions are discernible in the torque test. The untreated test yielded a result of 7.20 N.m., as seen in the graph. The outcome improved to 8.22 N.m. in the advanced torque test when injection was 50 and ignition was 10. Another increase to 8.25 N.m. occurred in the injection 100 and ignition 20 test. Results dropped back down to 8.24 N.m. in the test using a 50-millimeter injection advance and a 10-millimeter ignition. However, when the injection was advanced by 100 and the ignition by 20, the result dropped back down to 8.08 N.m.

When comparing untreated power and torque, injection was 50 points ahead of schedule, 100 points ahead of schedule, and 20 points behind, respectively. In the other direction, injection was 50 points behind schedule and 10 points behind, and 100 points behind schedule and 20 points behind. Without treatment, the graph shows that the 4-stroke motorcycle's power and torque were affected by injection timings of 50 ms and ignition delays of 10, 100 ms and ignition delays of 20, 50 ms and ignition delays of 10, and 100 ms and ignition delays of 20. Three separate tests yielded an average untreated power of 4.54 kW. The result dropped to 4.87 kW in the test with advanced injection 50/10. A boost to 5.48 kW was observed in the experiment using injection 100 and ignition 20. In the meantime, the power test with injection advanced by 50/10 resulted in a fall to 5.46 kW, and the result was even worse with injection advanced by 100 and ignition advanced by 20. The torque test then reveals the difference. The average result without therapy was 6.86 N.m., as shown in the graph, across three tests. With injection 50/10, the result improved to 7.10 N.m. in the advanced torque test. It went up to 8.27 N.m. again in the test with 100 injections and 20 ignitions. The test with 50 injections and 10 ignitions showed a return to 8.25 N.m., though. It dropped back down to 8.14 N.m. in the test with 100 injections and 20 ignitions [17,18].

The power and torque tests were conducted by the researchers based on the best emission results from a mixture of 40% pertamax and 60% ethanol [19, 20]. The findings were obtained. The above power and torque graph shows the variation between the untreated, advanced, retarded, and 100 ign groups in terms of power and torque. The graph clearly shows that in the untreated test, the 4-stroke motorbike's power and torque are affected by advanced inj 50 ign 10, retarded inj 100 ign 20, and inj 100 ign 20. The power test advanced inj 50/10 reduced the results to 4.87 Kw, while the test inj 100 ign 20 resulted in an increase to 5.48 Kw. The test was performed three times, and the average power results without treatment were 4.54 Kw. The results dropped to 5.46 kw in the power test with 50 kilowatts of backed-inJ and 5.33 kilowatts in the test with 100 kilowatts of ign 20. then the variation becomes apparent in the torque test. Looking at the graph, we can observe that after three tests without treatment, the average result was 6.86 N.m. However, after advancing the inj 50–10 in the torque test, the result increased to 7.10 N.m. In the inj 100–ign–20 test, it increased again to 8.27 N.m. Then, after reversing the inj 50–10, the result decreased to 8.25 N.m. Finally, after inj 100–ign–20 test, it decreased to 8.14 N.m.

4 Conclusion

The study found that 4-stroke motorbikes that were converted to EFI systems and used pertalite gasoline had a 39.13% (or 0.63% reduction) in CO content in their exhaust emissions. There was a clear and substantial rise of 68.99%, or 2.67%, in the CO2 content of exhaust emissions from 4-stroke motorcycles that were converted to EFI and used pertalite fuel. In contrast, 4-stroke motorbikes equipped with an electronic fuel injection system had a 4.33% drop in power, or 0.23 kw, and a 6.95% drop in torque, or 0.57 kw, after the upgrade. The optimal CO concentration in exhaust emissions from 4-stroke EFI motorbikes was measured in a mixture of 80% pertelite fuel and 20% ethanol, with a CO level of 1.21%. The most effective combination of pertalite gasoline and ethanol for 4-stroke EFI motorcycles produced the lowest CO2 emissions, with a concentration of 3.26% and HC levels of 76 parts per million. On a four-stroke motorbike, the ideal ethanol ratio is 60% pertalite gasoline and 40% ethanol, but this combination causes the engine to overheat.

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