



Air-Fuel Ratio Evaluation in Open-Loop ECU Mapping for a KZR Engine: A Trade-Off Analysis of Power, Torque, and Fuel-Efficiency Potential

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Abstract

An open-loop ECU operates without oxygen-sensor feedback, making Air-Fuel Ratio (AFR) control dependent on the preset fuel map. This study evaluated how three AFR settings in open-loop ECU mapping relate to the performance characteristics of a Honda KZR engine. A dynamometer-based experiment was conducted on a Honda Vario 125 KZR engine using Pertalite RON 90 and AFR targets of 11.7, 13.1, and 14.1. The evaluated parameters were engine power, torque response, and fuel-efficiency potential inferred from AFR characteristics. The results showed that AFR 13.1 produced the highest reported power output of 11.0 HP, whereas AFR 14.1 indicated a more favourable fuel-efficiency potential. AFR 11.7 represented an over-rich setting with the least favourable efficiency tendency. These findings indicate a trade-off between performance-oriented and economy-oriented AFR settings in open-loop ECU mapping.

Keywords

Open-loop ECU mapping; Air-Fuel Ratio; programmable ECU; KZR engine; dynamometer testing.

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INTRODUCTION

The development of automotive technology, particularly in motorcycle fuel-management systems, has continued to advance in response to the need for better engine performance, improved fuel utilization, and lower exhaust emissions. In modern spark-ignition motorcycles, the Electronic Control Unit (ECU) plays a central role in managing fuel injection, ignition timing, and Air-Fuel Ratio (AFR), which together determine combustion quality and engine response under different operating conditions. Recent studies on motorcycle electronic systems have shown that electronic control strategies are increasingly important for shaping performance characteristics, especially when fuel delivery and ignition parameters are adjusted for specific operating targets [1]. In closed-loop control strategies, AFR regulation can be supported by oxygen-sensor feedback, allowing the system to adjust fuel delivery in response to combustion conditions. Such feedback-based control has been shown to support more stable combustion and fuel-conversion efficiency because the controller can respond to changes in engine operation more adaptively [2].

Despite the advantages of closed-loop control, open-loop ECU mapping remains widely used in motorcycle modification and performance tuning because it allows the tuner to set predetermined fuel-map values without relying on real-time oxygen-sensor correction. This approach provides flexibility in adjusting fuel delivery, ignition-related parameters, and AFR targets according to the intended performance character. However, because open-loop mapping does not automatically correct the fuel mixture during operation, the final combustion



response depends strongly on the accuracy of the preset fuel map. Previous work on ECU-based fuel injection systems has shown that injection timing, injection duration, and fuel-system calibration affect engine output and must be adjusted carefully to obtain appropriate performance characteristics [3]. In the context of motorcycle engine testing, studies published in AEEJ have also demonstrated that changes in fuel-system configuration, injection conversion, venturi size, compression ratio, fuel additives, and fuel-use characteristics can influence power, torque, and fuel economy-related behaviour [4]–[7].

AFR is one of the most important parameters in fuel-injected spark-ignition engines because it represents the balance between air and fuel supplied for combustion. A mixture that is too rich may provide sufficient fuel for power production but can reduce combustion completeness and increase fuel use. Conversely, a mixture that is closer to the stoichiometric region may improve fuel-use tendency but may not always produce the highest power output under performance-oriented conditions. A recent review on excess air ratio in gasoline engines explains that changes in air–fuel mixture composition are closely linked to emissions, performance, efficiency, specific fuel consumption, and combustion stability [8]. Therefore, selecting an AFR target in an open-loop ECU system should not be treated as a single-direction performance improvement strategy; rather, it should be understood as a calibration decision involving trade-offs among power, torque, combustion quality, and fuel-efficiency potential.

Several recent studies support the importance of AFR and ECU calibration in small spark-ignition engines. Experimental work on AFR control using an external engine-management system showed that AFR adjustment can contribute to more efficient fuel use under specific operating conditions [9]. Another study on gasoline–ethanol–methanol fuel mixtures reported that variations in lambda or AFR altered torque, power, and specific fuel consumption in a 125 cc electronic fuel-injection motorcycle engine [10]. Research on ECU remapping in a 150 cc four-stroke motorcycle engine also showed that adjustments in fuel delivery, ignition timing, and AFR can change the torque–power envelope and emission behaviour [11]. Similarly, a fuel-injected motorcycle study using Pertalite–ethanol blends and ECU-based optimization reported that fuel composition and ECU strategy are closely related to efficiency improvement and emission reduction [12]. These studies collectively indicate that ECU mapping and AFR calibration are technically relevant for motorcycle engine performance evaluation.

However, most previous studies have examined ECU modification, ignition timing, fuel variation, or engine-performance parameters separately. Limited attention has been given to the comparative evaluation of several AFR targets in an open-loop ECU setting while simultaneously considering power, torque, and fuel-efficiency potential in a KZR engine. This gap is important because the KZR engine is commonly used in small motorcycles and is frequently selected for standard use as well as practical modification. Since the open-loop ECU system relies on predetermined mapping values, an inappropriate AFR target may produce either an over-rich mixture with inefficient fuel utilization or a leaner mixture that does not provide the desired power response. Therefore, an experimental evaluation is needed to identify how selected AFR settings shape the performance characteristics of this engine type.

Based on this background, this study evaluates the relationship between open-loop ECU mapping with different AFR targets and the performance characteristics of a Honda KZR engine. The tested AFR values are 11.7, 13.1, and 14.1, and the evaluation focuses on engine power, torque response, and fuel-efficiency potential inferred from AFR characteristics. The contribution of this study lies in providing an experimental comparison of AFR settings in open-loop ECU mapping for a KZR engine and offering preliminary technical insight into the trade-off between performance-oriented and economy-oriented calibration strategies. The findings are expected to support ECU tuners, automotive practitioners, and researchers in selecting AFR settings more carefully for small motorcycle engines under comparable testing conditions.

METHOD

This study employed an experimental method to evaluate the relationship between open-loop Electronic Control Unit (ECU) remapping and the performance characteristics of a Honda KZR engine. The experimental unit was a Honda Vario 125 motorcycle equipped with a KZR engine, with a displacement of 124.8 cc, a four-stroke SOHC two-valve configuration, liquid cooling, and a PGM-FI fuel-injection system. Pertalite fuel with a Research Octane Number (RON) of 90 was used throughout the experiment to maintain consistency in fuel characteristics. The ECU remapping process was performed using a BRT Juken 5 Racing Turbo programmable ECU. Three target Air-Fuel Ratio (AFR) settings were tested, namely 11.7, 13.1, and 14.1. The AFR value was monitored in real time using a Bosch LSU 4.9 wideband oxygen sensor calibrated according to the manufacturer's procedure.

The overall experimental procedure is summarized in Figure 1. The procedure began with a preparation phase, which included assessing the condition of the Honda Vario 125 engine and calibrating the measurement instruments. The next stage was ECU configuration, in which the BRT Juken 5 ECU was programmed into open-loop mode using Pertalite RON 90 fuel. After the ECU configuration was completed, the fuel map was adjusted to the three target AFR settings. Each AFR configuration was then tested using a chassis dynamometer through a sweep-test method. The recorded data were subsequently used for descriptive quantitative analysis to compare the maximum power and torque characteristics across the AFR variations.

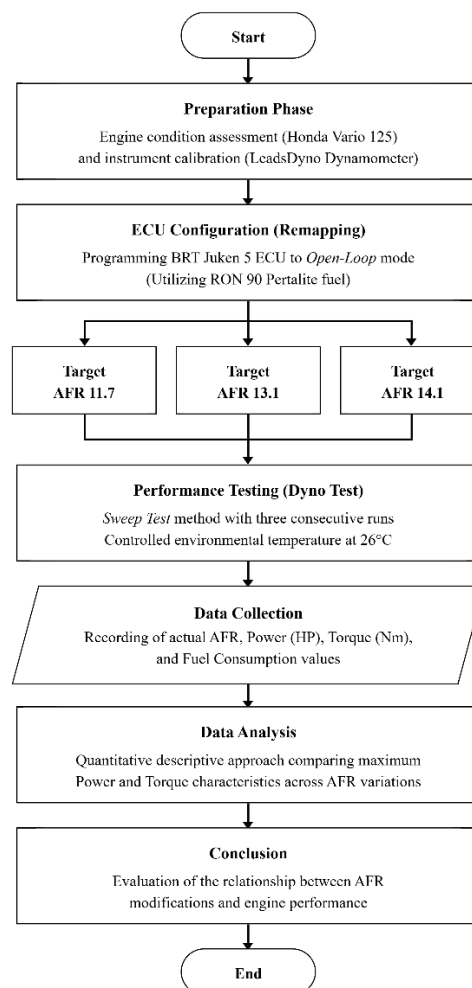


Figure 1. Experimental workflow for open-loop ECU mapping and dynamometer-based performance testing

Engine performance testing was conducted in a laboratory using a Leads Dyno chassis dynamometer with a flywheel inertia of $3 \text{ kg}\cdot\text{m}^2$. Sport Dyno V4 software was used as the data-acquisition system. The dynamometer system applied an automatic correction factor based on ISO 1585 to compensate for atmospheric variation during testing. In this study, the correction standard was used as a reference for reporting power-related performance data, while the test interpretation remained limited to the motorcycle and chassis-dynamometer conditions used in the experiment [13]. The test environment was maintained under controlled laboratory conditions, with the ambient temperature recorded at approximately $26\text{--}28^\circ\text{C}$ during testing. The sweep-test mode was selected to obtain power and torque curves over the engine-speed operating range.

The AFR monitoring procedure used a wideband oxygen sensor because this type of sensor is commonly used to observe air–fuel mixture conditions by measuring oxygen concentration in exhaust gases [14]. The use of controlled laboratory testing, synchronized data acquisition, and recorded environmental parameters was intended to improve the consistency of the performance measurements. Similar experimental assessments of spark-ignition engines emphasize the importance of recording operating conditions and using stable test procedures when evaluating engine performance and combustion-related behaviour [15]. In this study, the programmable ECU was used only to adjust the target AFR settings, while other ECU parameters not included as research variables were maintained as constant as possible. This approach was used to ensure that the observed performance differences were mainly associated with the AFR variations generated by the open-loop remapping configuration. The use of reprogrammable ECUs in spark-ignition engine testing enables precise regulation of fuel-delivery parameters during experimental calibration [16].

Each AFR configuration was tested through three consecutive runs under the same vehicle condition and without mechanical component changes. Before data collection, the engine was warmed up until it reached normal operating temperature to reduce variation caused by unstable thermal conditions. The controlled variables included fuel type, engine specification, ignition system condition, vehicle condition, ECU device, AFR sensor, and laboratory test environment. The independent variable was the open-loop ECU mapping setting represented by the target AFR values of 11.7, 13.1, and 14.1. The dependent variables were actual AFR, engine power, engine torque, and fuel-consumption-related values recorded or generated during testing. The control variables included the fuel used, ambient test condition, and the standard test-worthy engine condition.

The research procedure consisted of four main stages. First, the preparation stage involved checking the engine condition to ensure that the motorcycle system operated properly and preparing the measurement instruments before testing. Second, the ECU configuration stage involved setting the programmable ECU to open-loop mode and applying the three target AFR values to the same fuel-map area within the engine-speed and throttle-opening range used during data collection. Other ECU parameters, including ignition timing, engine-speed limit, and control parameters outside the research variables, were maintained unchanged. Third, the dynamometer testing stage was conducted to measure engine power and torque under each AFR configuration. Fourth, the data collection stage involved recording actual AFR, power, torque, vehicle speed, engine speed, environmental temperature, humidity, atmospheric pressure, and fuel-consumption-related values when available from the test system.

The data were recorded digitally using the dynamometer software. For each AFR variation, the maximum power and maximum torque values were identified from the dyno test curves and summarized as the basis for comparison. The data were analysed using a descriptive quantitative approach by presenting the results in tables and graphs, comparing the maximum power and torque characteristics for each AFR setting, and evaluating the observed tendency

between AFR variation, engine performance, and fuel-efficiency potential. Because the analysis was descriptive and based on the tested AFR settings, the interpretation was limited to the experimental conditions, engine type, fuel type, ECU configuration, and dynamometer setup used in this study.

RESULT AND DISCUSSION

Results

The engine performance test was conducted on a Honda Vario 125 KZR engine under three Air-Fuel Ratio (AFR) settings, namely 11.7, 13.1, and 14.1. The test outputs were obtained from the dynamometer system and are presented through numerical data and power-torque curves for each AFR configuration. The results focus on maximum power, maximum torque, vehicle speed, engine speed, and environmental test conditions recorded during the dyno test.

The first test was conducted using an AFR setting of 11.7. The dyno test output for this configuration is summarized in Table 1, while the corresponding power and torque curves are presented in Figure 2.

Table 1. Dynotest result for AFR 11.7

Test configuration	Max power	Max torque	Max vehicle speed	Engine speed	Temperature	Humidity	Pressure
Honda Vario 125 KZR, AFR 11.7	10.7 HP	19.54 N·m	105.1 km/h	0-14490 rpm	26.2°C	88.60%	936.6

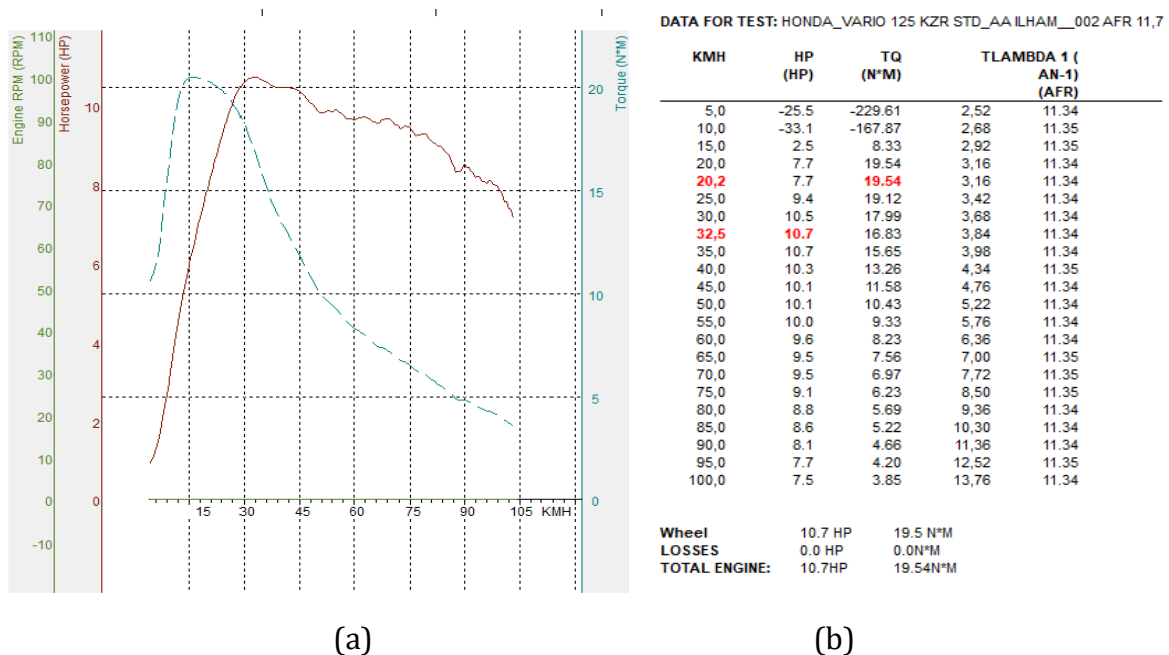


Figure 2. Power-torque curve and numerical dyno test output of the Honda Vario 125 KZR engine at AFR 11.7: (a) vehicle speed, power, and torque curve; (b) numerical dyno test output.

As shown in Table 1 and Figure 2, the AFR 11.7 configuration produced a maximum power of 10.7 HP and a maximum torque of 19.54 N·m. The maximum vehicle speed recorded in this test was 105.1 km/h, with the engine-speed output recorded up to 14490 rpm. The test was conducted at an ambient temperature of 26.2°C, humidity of 88.6%, and atmospheric pressure of 936.6.

The second test was conducted using an AFR setting of 13.1. The dynotest output for this configuration is summarized in Table 2, and the corresponding power and torque curves are shown in Figure 3.

Table 2. Dynotest result for AFR 13.1

Test configuration	Max power	Max torque	Max vehicle speed	Engine speed	Temperature	Humidity	Pressure
Honda Vario 125 KZR, AFR 13.1	10.9 HP	25.78 N·m	105.5 km/h	0–14543 rpm	27.5°C	83.1%	936.6

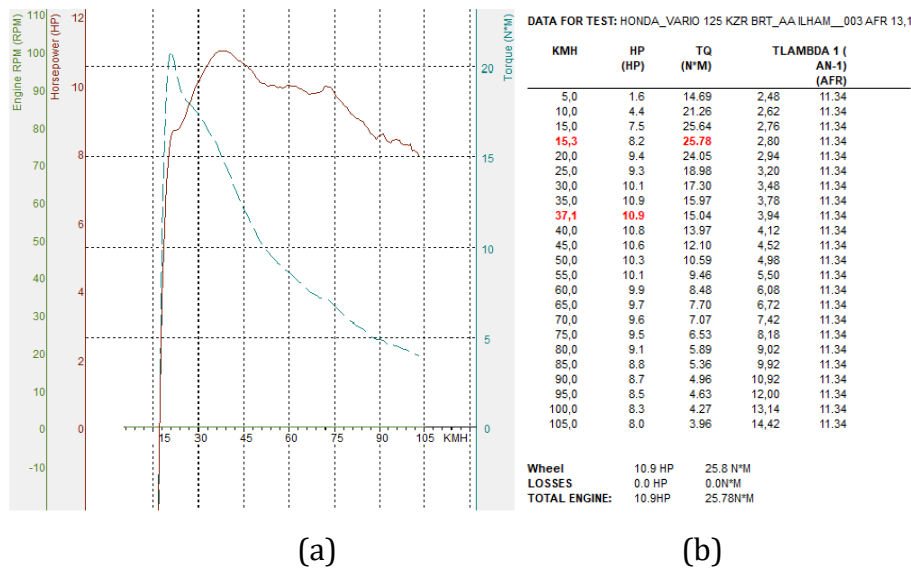


Figure 3. Power–torque curve and numerical dyno test output of the Honda Vario 125 KZR engine at AFR 13.1: (a) vehicle speed, power, and torque curve; (b) numerical dyno test output.

Based on Table 2 and Figure 3, the AFR 13.1 configuration produced a maximum power of 10.9 HP and a maximum torque of 25.78 N·m. The maximum vehicle speed recorded in this test was 105.5 km/h, with the engine-speed output recorded up to 14543 rpm. The test was conducted at an ambient temperature of 27.5°C, humidity of 83.1%, and atmospheric pressure of 936.6.

The third test was conducted using an AFR setting of 14.1. The dyno test output for this configuration is summarized in Table 3, while the power and torque curves are presented in Figure 4.

Table 3. Dyno test result for AFR 14.1

Test configuration	Max power	Max torque	Max vehicle speed	Engine speed	Temperature	Humidity	Pressure
Honda Vario 125 KZR, AFR 14.1	10.9 HP	22.76 N·m	105.4 km/h	0–14540 rpm	27.0°C	85.8%	936.7

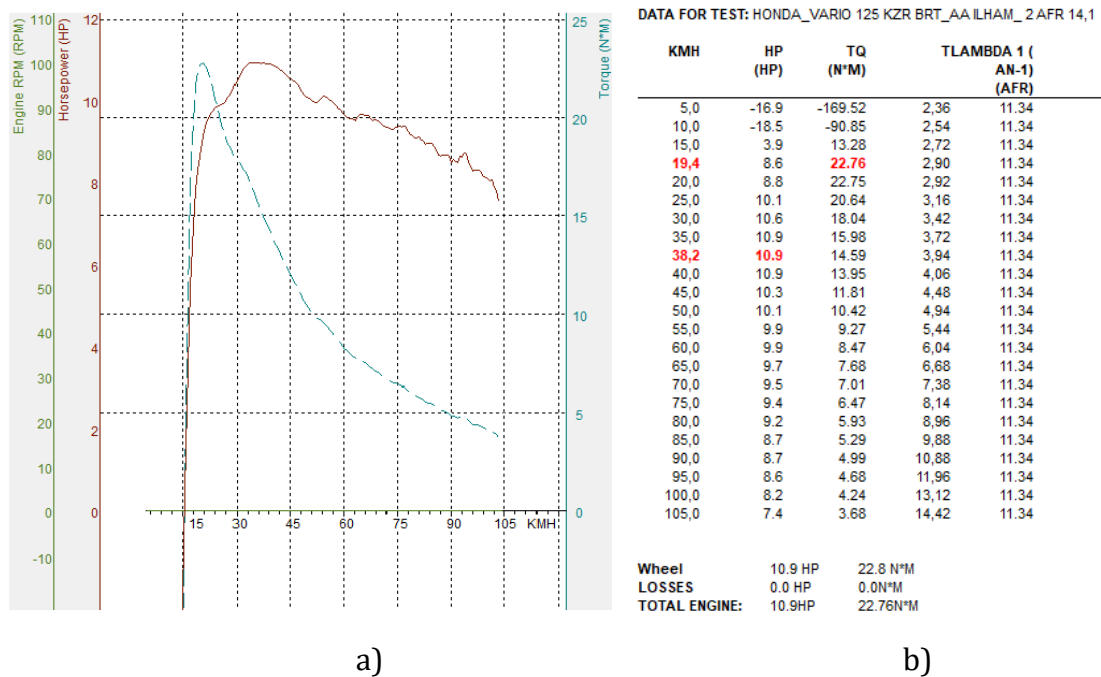


Figure 4. Power–torque curve and numerical dyno test output of the Honda Vario 125 KZR engine at AFR 14.1: (a) vehicle speed, power, and torque curve; (b) numerical dyno test output.

As presented in Table 3 and Figure 4, the AFR 14.1 configuration produced a maximum power of 10.9 HP and a maximum torque of 22.76 N·m. The maximum vehicle speed recorded in this test was 105.4 km/h, with the engine-speed output recorded up to 14540 rpm. The test was conducted at an ambient temperature of 27.0°C, humidity of 85.8%, and atmospheric pressure of 936.7.

Overall, the dyno test results show that different AFR settings produced different power and torque characteristics. The AFR 11.7 configuration generated 10.7 HP and 19.54 N·m. The AFR 13.1 configuration generated 10.9 HP and produced the highest recorded torque, namely 25.78 N·m. The AFR 14.1 configuration also generated 10.9 HP, with a lower maximum torque than AFR 13.1 but higher than AFR 11.7. These results indicate that the main difference among the tested AFR configurations was more clearly reflected in the torque output than in the maximum power output.

Discussion

The dyno test results indicate that the tested AFR mapping settings produced different power and torque characteristics on the Honda Vario 125 KZR engine. To support a more focused interpretation, the main performance values obtained from the Results section are summarized in Table 4. This table continues the numbering from the Results section and is used as an interpretive summary of the measured dyno test outputs, not as a separate measurement.

Table 4. Summary of AFR mapping settings and engine performance characteristics

No.	Target AFR setting	Max power	Max torque	Performance tendency
1	11.7	10.7 HP	19.54 N·m	Lower power and torque output
2	13.1	10.9 HP	25.78 N·m	Highest recorded torque with comparable power output

No.	Target AFR setting	Max power	Max torque	Performance tendency
3	14.1	10.9 HP	22.76 N·m	Comparable power with lower torque than AFR 13.1

Based on [Table 4](#), the difference among the three AFR settings was more clearly reflected in torque than in maximum power. The AFR 11.7 setting produced 10.7 HP and 19.54 N·m, while the AFR 13.1 setting produced 10.9 HP and the highest recorded torque of 25.78 N·m. The AFR 14.1 setting also produced 10.9 HP, but its maximum torque was lower than AFR 13.1, namely 22.76 N·m. This pattern indicates that the tested AFR mapping settings did not produce a large difference in maximum power between AFR 13.1 and AFR 14.1, but they produced a clearer difference in torque response. Therefore, the discussion should emphasize the torque response and performance trade-off rather than claiming a large power advantage for one AFR setting.

The difference in torque response can be interpreted from the perspective of mixture formation and combustion stability. AFR control is an important factor in internal combustion engines because mixture composition affects combustion quality, fuel utilization, emissions, engine response, and durability [17]. In a feedback-based system, AFR can be corrected through sensor information, while in an open-loop ECU system, the fuel mixture depends on the preset fuel-map configuration. Studies on AFR control have emphasized that the absence or failure of accurate feedback can affect mixture regulation and operating stability, particularly when the engine faces changing load or speed conditions [18]. In the present study, the open-loop configuration means that the observed performance pattern is closely related to how the selected target AFR settings were programmed and how the engine responded under dyno test conditions.

The relatively low torque at AFR 11.7 may be associated with an overly rich mixture tendency. A rich mixture may support combustion under high-load conditions, but excessive fuel supply can reduce combustion completeness if the available oxygen is insufficient. This can limit the conversion of fuel energy into useful torque. A comparable motorcycle study using an aftermarket ECU showed that additional fuel delivery through ECU modification may increase power and torque, but it can also increase fuel consumption and emissions when calibration is not balanced [19]. Similarly, experimental work on different ECU, injector, and spark-plug configurations showed that changes in fuel and ignition-related components can alter power and torque output, but the performance result depends on the suitability of the entire combustion setup rather than the ECU alone [20]. These findings help explain why a richer AFR setting does not automatically produce the best output in every condition.

The AFR 13.1 setting produced the highest recorded torque in this study. This result suggests that, under the tested conditions, this setting provided a more suitable balance between fuel availability and air supply for torque production. In small motorcycle engines, torque output is strongly affected by combustion pressure development, mixture preparation, ignition condition, and fuel-injection behaviour. A study on high-concentration gasoline-ethanol-methanol blends in a single-cylinder spark-ignition engine showed that AFR and fuel properties are closely related to torque and power characteristics during chassis-dynamometer testing [21]. Another study on ECU racing and injector racing in a motorcycle engine reported that changes in ECU and injector configuration affected torque, power, and fuel-consumption behaviour [22]. Compared with those studies, the present findings strengthen the view that ECU-related calibration can shape engine output, but the best configuration depends on the tested engine, fuel, and operating condition.

The AFR 14.1 setting produced the same maximum power as AFR 13.1 but lower torque. This pattern suggests that a leaner or more stoichiometric-oriented mapping tendency may still maintain peak power under the tested condition, but it did not produce the same torque response as AFR 13.1. This finding is important because it shows that power and torque do not always change in the same proportion. Studies on programmable ECU settings have shown that changes in ignition timing, injection duration, and ECU configuration can produce different responses in power and torque because each parameter affects combustion phasing and energy release differently [23], [24]. Therefore, the AFR 14.1 result should not be interpreted simply as “worse” than AFR 13.1, but rather as a different calibration tendency that may be more suitable for conditions where economy-oriented operation is prioritized, provided that actual fuel-consumption data support this interpretation.

The combustion tendency of each AFR setting can be summarized cautiously in Table 5. This table should be read as an interpretive classification based on AFR mapping and performance behaviour, not as measured fuel-consumption evidence.

Table 5. Interpretive combustion tendency based on AFR mapping variation

No.	Target AFR setting	Mixture tendency	Combustion and fuel-use interpretation
1	11.7	Very rich	Potentially higher fuel use and lower combustion completeness if oxygen availability is insufficient
2	13.1	Rich performance-oriented	More favourable balance for torque production under the tested dyno test condition
3	14.1	Closer to stoichiometric tendency	Potentially more favourable fuel-use tendency, but with lower torque than AFR 13.1

Based on Table 5, AFR 14.1 may be interpreted as having a more favourable fuel-efficiency potential than the richer configurations because it represents a mixture tendency closer to stoichiometric combustion. However, this interpretation must remain cautious because the Results section does not present direct fuel-consumption, fuel-flow, brake-specific fuel-consumption, or thermal-efficiency data. Previous work on spark-ignition engine parameters has shown that engine performance is affected not only by fuel mixture but also by ignition timing, engine speed, load, and fuel properties [25]. Research on variable excess air ratio and ignition timing also indicates that mixture composition can improve efficiency or emissions under certain conditions but may reduce maximum torque or power when the mixture becomes less favorable for high-load combustion [26]. Therefore, in the present study, AFR 14.1 can only be discussed as having fuel-efficiency potential, not as a measured fuel-efficiency improvement.

The comparison between Figure 2, Figure 3, and Figure 4 further supports the interpretation that torque response is the main differentiating output among the tested AFR settings. Figure 2 shows that the AFR 11.7 configuration produced the lowest maximum torque, while Figure 3 shows a stronger torque response under AFR 13.1. Figure 4 indicates that AFR 14.1 maintained comparable power to AFR 13.1 but did not reach the same torque value. This pattern suggests that the KZR engine response to open-loop AFR mapping is not linear across the tested settings. Increasing the AFR target from 11.7 to 13.1 was associated with a clear torque improvement but increasing it further to 14.1 did not further increase torque. Thus, the tested data support a trade-off interpretation rather than a simple “higher AFR is always better” or “richer AFR is always stronger” conclusion.

From a practical standpoint, the findings suggest that AFR 13.1 can be considered a performance-oriented mapping option for the tested Honda Vario 125 KZR engine because it produced the highest recorded torque while maintaining maximum power comparable to AFR 14.1. Meanwhile, AFR 14.1 may be considered for economy-oriented calibration, but this implication requires direct fuel-consumption testing before it can be claimed as more fuel efficient. AFR 11.7 appears less favourable under the tested condition because it produced the lowest power and torque outputs. These implications are limited to the tested engine, Pertalite RON 90 fuel, BRT Juken 5 Racing Turbo ECU configuration, dyno test procedure, and the selected AFR settings. Broader generalization to other engines, fuels, ECU maps, or riding conditions should be made cautiously.

CONCLUSION

Conclusion

This study evaluated open-loop ECU remapping with three AFR settings on the performance characteristics of a Honda Vario 125 KZR engine. The results showed that different AFR settings produced different power and torque responses under the tested dynamometer conditions. AFR 13.1 produced the highest recorded torque of 25.78 N·m while maintaining a maximum power output comparable to AFR 14.1. In contrast, AFR 11.7 produced the lowest power and torque values among the tested configurations. These findings indicate that AFR 13.1 can be considered a more performance-oriented mapping option for the tested engine, particularly in terms of torque response.

AFR 14.1 showed a comparable maximum power output but lower torque than AFR 13.1, suggesting a different calibration tendency that may be more suitable for economy-oriented operation. However, this interpretation should be treated as fuel-efficiency potential because direct fuel-consumption data were not presented. Overall, the study demonstrates that selecting an AFR setting in open-loop ECU mapping requires careful consideration of the trade-off between power, torque, and fuel-use tendency. Future studies should include direct fuel-consumption or BSFC measurements, broader AFR variations, and closed-loop feedback control to evaluate AFR stability under changing engine speed and load conditions.

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