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ANALYSIS OF EXHAUST EMISSIONS, NOISE, AND PERFORMANCE OF A 110CC MOTORCYCLE USING A PERFORATED-CLOSE CONICAL SILENCER MUFFLER

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Abstract

This paper analyzes the problem of increasing high motorcycle performance through the use of racing exhausts but with noise levels and exhaust emissions that meet the provisions of the Indonesian government. The purpose of this study is to conduct emission testing experiments, performance tests, and noise tests using PCCS exhaust technology. This study adopts an experimental method involving three tests: exhaust emission testing based on the SNI 09-7118.1-2005 standard, noise measurement using the static test procedure according to the UN-R 41-04 standard, and performance evaluation conducted with an inertial dynamometer. Implementing the PCCS exhaust system on a 110 cc automatic motorcycle positively impacts exhaust emissions, noise levels, and engine performance. Compared to the standard exhaust, the PCCS significantly reduces CO and HC emissions by 78.99% and 55.99%, respectively, while maintaining noise levels within regulatory limits in urban conditions. In terms of performance, the PCCS delivers higher torque and power output, particularly in the 3500–5500 RPM range, which aligns with typical riding conditions. These improvements are attributed to the system's efficient exhaust flow and reduced backpressure.

Keyword: Emissions, Muffler; Noise, Perforated-Close Conical Silencer; Performance

INTRODUCTION

Indonesia is the highest motorcycle user in ASEAN, with 143,797,227 units [1], domestic sales of 5,221,470 units, and exports of 743,551 units [2]. The data is for motorcycles produced by the Indonesian Sole Brand Holder Agent of the ICE (Internal Combustion Engine) type. The increasing number of motorcycles in urban and suburban areas contributes to increasing noise levels, which can cause adverse health effects such as hearing loss, cardiovascular disease, and psychological stress [3]. Excessive noise also reduces the quality of life in residential areas and affects biodiversity by disturbing wildlife [4]. Noise affects hearing, and noise can increase adrenaline, constrict blood vessels, increase blood pressure, increase thyroid hormones, cause rapid heartbeat, and affect various body functions [5].

To reduce the adverse effects of excessive noise, the Indonesian government has implemented regulations on motorcycle noise through Permen LHK NO 56 of 2019 [5]. In addition, international standards such as the European Union (EU) and the United Nations Economic Commission for Europe (UNECE) have regulated vehicle noise emissions through testing protocols such as ISO 5130:2020 [9]. Many ICE motorcycle users in Indonesia replace standard exhausts with "freeflow" racing exhausts to increase performance, both torque and motor power, but have an impact on increasing noise [6-7]. The use of racing exhausts is prohibited on the highway because it violates the noise limit value for wide open throttle (WOT) of two-wheeled motor vehicles with a Power Mass Ratio PMR between 25 and 50 is 79dB while PMR> 50 is 82 dB. Despite these regulations, modifications to the exhaust system have become standard practice and have caused an increase in noise emissions beyond the permitted limits.

In addition, the requirements for roadworthy ICE vehicles are that exhaust emissions must meet the regulations of the Minister of Environment and Forestry Regulation No. 8 of 2023 [10] with a CO content of 3% and HC 1000 ppm. This regulation replaces the Minister of Environment and Forestry Regulation No. 5 of 2006 [11] with a CO limit of 4.5% and HC 2000ppm. Exhaust emissions in the form of Nitrogen Oxide (NOx), carbon monoxide (CO), Hydrocarbons (HC), and particulates harm the environment [12]. The government has addressed this with Government Regulation No. 33 of 2023, one of the forms of which is a program to convert gasoline to electric motors. However, the program has not been implemented massively due to the high conversion costs and the long process of obtaining STNK-BPKB. Exhaust emissions can be reduced before, during, and after combustion [13]. Exhaust emissions are reduced by adding a catalytic converter. Catalytic converter research using various active materials can reduce HC and CO values by more than 20% [14-16]. Catalytic converters are a solution to reduce emissions [17-20].

Many simulation studies and experiments on racing exhausts are to obtain low noise values and improve vehicle performance [22-42], but none have studied simultaneously reducing exhaust emissions and meeting government regulations regarding exhaust emissions and noise values. Advances in acoustic engineering have introduced noise-reducing technology to reactive and absorptive exhausts, which aim to reduce exhaust noise without sacrificing engine performance [43].

Overcoming the problem of increasing high motorcycle performance through the use of racing exhausts but with noise and exhaust emissions that meet Indonesian government regulations, the purpose of this study is to conduct emission testing experiments, performance tests, and noise tests using PCCS (Perforated-Close Conical Silencer) exhaust technology based on registered patent IDS000008762 and the addition of a catalytic converter placed on the inlet. The PCCS exhaust uses closed and open cones inside the silencer to divide the laminar flow from the exhaust header into turbulent and laminar flows, resulting in high exhaust gas flow rates but low noise levels (Figure 1).

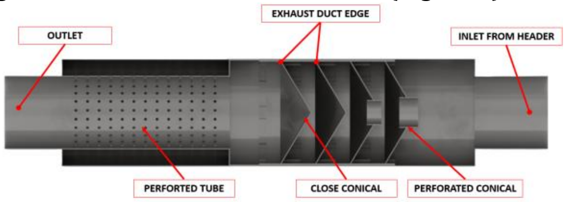

Figure 1. PCCS Muffler Design

The novelty of this study is analyzing the exhaust emission, noise, and performance of 110cc motorcycles experimentally through the use of PCCS exhausts compared to standard exhausts.

METHODS

This study uses an experimental method with the exhaust emission test using the SNI 09-7118.1-2005 standard. The carbon monoxide (CO) and hydrocarbon (HC) emission test method for motorcycles at idle speed with the setup shown in Figure 2. The noise test method employs a static testing procedure that adheres to the UN-R 41-04 standard, as outlined in the Regulation of the Minister of Environment and Forestry No. 56 of 2019. The setup for the static noise test is illustrated in Figure 3. The performance test uses an inertial dynamometer (dyno test) test machine with the test setup shown in Figure 4. The entire test was carried out 5 times and averaged to analyze the differences.

Figure 2. Vehicle exhaust emission test setup

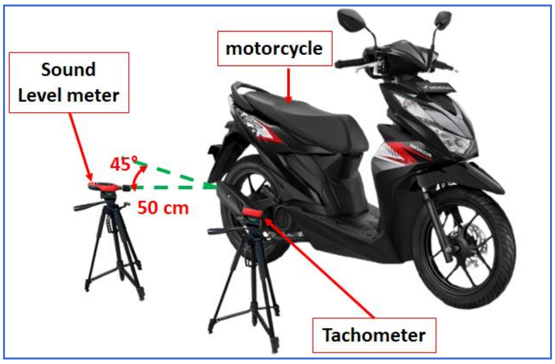

Figure 3. Vehicle static noise test setup

Figure 4. Vehicle performance test setup

The research location is in the Unnes Mechanical Engineering performance test lab for the noise test location, the AR speed racing workshop for the performance test, and the SMKN Jateng two-wheeled competency test location workshop. Table 1 displays the equipment utilized in the study. The test was conducted from December 2023 to January 2024.

Research materials: standard exhaust (OEM) Honda Beat 110cc, PCCS silencer exhaust (Fig. 5a) and exhaust header of a 110cc motorcycle (Fig. 5b),

Table 1. Research test equipment

No	Tools and Functions	Specification	Value
1	Honda Beat 110cc 2023, 4 stroke Function: Tested vehicle	Cylinder (cc) Maximum power (kW) Maximum torque (Nm) Mass (kg) Transmission	109.5 6.6 9.3 88 V-matic
2	*Sound Level Meter*Krisbow type 10176592 Function: Noise value measuring tool	*Measuring level range* (dB) *Accuracy* (dB) *Frequency range* (Hz-kHz) *Resolution* (dB)	35 to 130 ±3 31.5 to 8 0.1
3	Digital Tachometer i-Max. Function: Tool for measuring rotational speed in units of time	Processor NXP LPC 92 series 12 MHz Measurement tolerance (RPM) RPM screen display	 +/- 20 0.0001 to 20.000
4	PRO DYNO 130HP (Dynamometer) Smart Power SP-1 Ver 3b Sport Devices Inertia Electronics Kit Function: Measuring tool for torque, power, rpm values.	Cylinder volume max (cc) Max power (hp) Number of wheels Type of sensor software Engine rpm input	1000 130 2 Digital Pick Up Sports device capacitive type
5	HESBON HG-520 gas analyzer Function: Measuring tool for exhaust gas emission levels from vehicle exhausts	CO2 range (%) CO range (%) HC range (ppm) O2 range (%) Lambda range	0.00-25.00 0.00-10.00 0-9999 0.00-25.00 0-2000
6	Honda Injection Diagnostic Tools HiDS Scanner, function: diagnose damage to injection system sensors	Type Brand Dimensions L x W x H (cm)	HD-30 Starnics 12 x 4 x 9

catalytic converter diameter 51mm stainless steel with honeycomb copper alloy as in Figure 6. Pertamax-type gasoline fuel with RON 92.

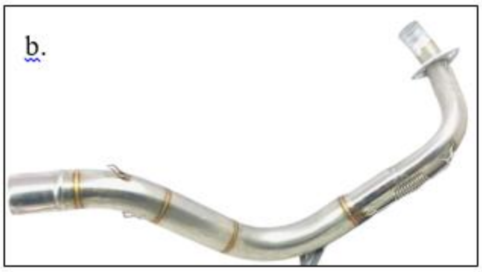

Figure 5. a. PCCS Silencer; b. Exhaust Header of a 110cc Motorcycle

Figure 6. Honeycomb model catalytic converter (https://www.temu.com)

According to UNECE Regulation No. 41 Revision 4 (UN R41-04), the Power-to-Mass Ratio (PMR) is calculated using Equation 1. The PMR value for a 110cc automatic motorcycle is provided in Table 2.

$$PMR = \left(\frac{P_n}{m_{kerb}+75}\right) x\ 1000 \quad (1)$$

where PMR is the power-to-mass ratio, P_n is the maximum net power of the machine (kW), m_{kerb} is the empty weight of vehicle (kg).

Table 2. PMR value of 110cc automatic motorcycle

Specification	P_n (kW)	m_{kerb} (kg)	PMR
Value	6.6	88	40.49

The threshold value for motorcycle noise according to Indonesian government regulations for new vehicles with a PMR of 40.49 (25 < PMR ≤ 50) is 74 dB for the L Urban category and 79 dB for L WOT [5]

Table 3. Motorcycle noise quality standards with a PMR of 25 < PMR ≤ 50

Power Mass Ratio (PMR)	Quality standards dB (A)		Method
	L Urban	L Wide Open Throttle	
25 < PMR ≤ 50	74	79	UN-R 41-04

RESULTS AND DISCUSSION

Analysis of exhaust emissions of standard and PCCS exhaust

The results of emission tests on 110 cc motorcycles, both carbon monoxide (CO) and hydrocarbon (HC) levels between the use of standard exhaust and PCCS exhaust, are presented in Table 4. Both exhausts have CO and HC levels that meet government regulations: CO levels <3% and HC < 1000 ppm.

Table 4. CO and HC values between the use of standard exhaust compared to PCCS

Exhaust type	Levels CO (%)	Levels HC (ppm)
Standard	2.47	160.667
PCCS	1.38	103
Thershold [10]	3	1000
% Different	78.99	55.99

PCCS exhaust produces lower CO and HC levels than standard exhaust, as shown in Figure 7. The difference in CO and HC levels from PCCS exhaust is 78.99% and 55.99% lower than standard exhaust, respectively. The PCCS exhaust features a catalytic converter that lowers CO and HC emissions.

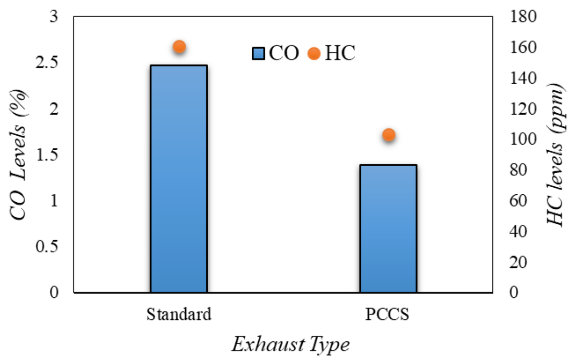

Figure 7. Exhaust type vs CO vs HC graph

The results of relevant studies on using catalytic converters with copper raw materials can be in the form of honeycomb reducing CO and HC gas emissions by up to 55.34% [17]. This study demonstrated that using copper as a catalytic converter material in exhaust systems can reduce exhaust emissions by up to 79.6% [20]. Adding a catalytic converter causes an oxidation reaction in CO and HC exhaust gases to become CO_2 and H_2O, making the exhaust gas more environmentally friendly [44].

Analysis of exhaust noises of standard and PCCS exhaust

The results of the noise test on a 110cc motorcycle using a PCCS exhaust and a standard exhaust in the L urban category are shown in Figure 8. Based on the noise limit regulation of the Minister of Environment and Forestry Regulation No. 56 of 2019 for a 110cc automatic motorcycle in the L urban category, it is ≤ 74dB. The noise test using both PCCS and standard exhausts using the UN-R 41-04 static test method at idle engine speed conditions on a 110cc motorcycle obtained results <74dB, meaning that both types of exhausts meet government regulations. A standard exhaust produces 71dB of noise, 3.94% lower than the PCCS exhaust (73.8dB). The use of a standard exhaust is still superior to the PCCS exhaust.

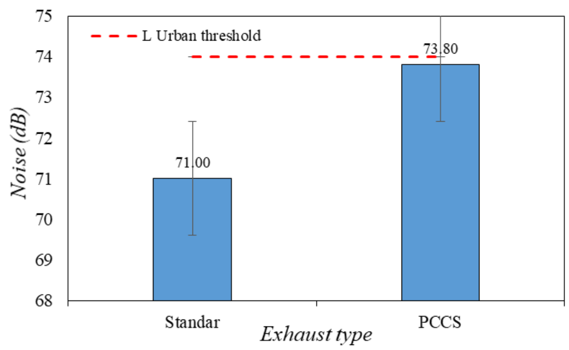

Figure 8. Exhaust type vs noise graph in the L Urban test

The graph of the difference in noise levels produced by a 110cc automatic motorbike using both types of exhaust and compared to the government regulation of category L Wide Open Throttle can be seen in Figure 9.

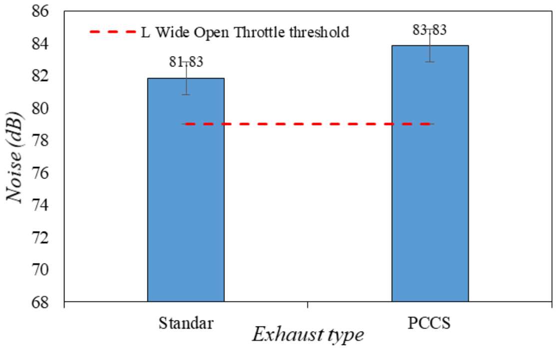

Figure 9. Exhaust type vs noise graph in the L wide open throttle test

The noise limit, according to the Minister of Environment and Forestry Regulation No. 56 of 2019, for motorcycles with 25 < PMR ≤ 50 category L WOT is ≤ 79 dB [5]. Motorcycle noise testing was conducted using the UN-R 41-04 method with a static test at an engine speed of 4500rpm. The results of the noise test with the L WOT category found that the use of a standard exhaust of 81.83 dB and a PCCS exhaust of 83.83 dB had exceeded the WOT threshold value (≤79 dB), so both types of exhausts did not meet government regulations. If the noise value is compared with the WOT threshold value, the noise value of the standard exhaust is 3.4% higher, while the PCCS exhaust is 6.1% higher. The use of this standard exhaust exceeds the noise quality standard limit, which the motorbike can cause used not to be a new vehicle but to have been used previously. Noise tests were conducted at engine speeds of 1500 (idle), 2000, 3000, and 4500 rpm for both types of exhaust, as shown in Figure 10.

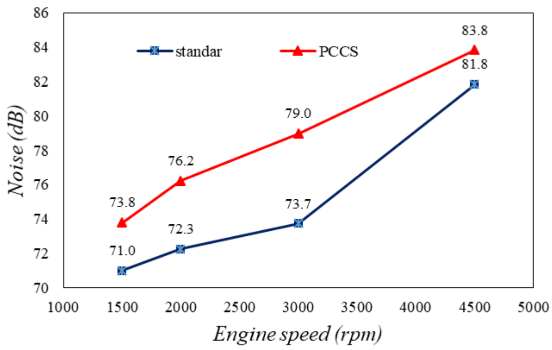

Figure 10. Graph of engine rotation speed vs noise of standard and PCCS exhaust

Based on the noise test result graph from various engine rotational speeds, the higher the engine speed, the higher the noise value. The standard exhaust noise test value and PCCS at 3000 rpm engine speed are 73.7 dB and 79dB, respectively, which still meet the noise threshold value of category 25 < PMR ≤ 50 L WOT, which is 79dB, but at 4500 rpm, the noise value has exceeded 81.8 dB and 83.8 dB. The difference in PCCS exhaust noise value is 7.1% higher than the standard exhaust.

Analysis of motorcycle performance test with standard and PCCS exhaust

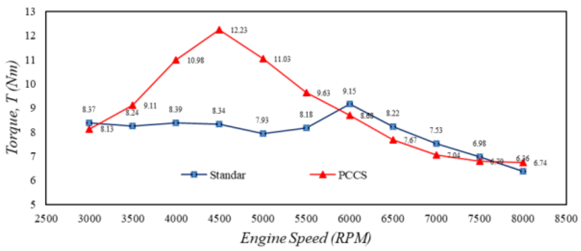

Figure 11. Graph of engine rotation speed vs torque of standard and PCCS exhaust

Figure 11 illustrates the relationship between engine speed (RPM) and torque output (Nm) for two different exhaust systems: a standard exhaust and a PCCS. The data spans engine speeds from 3000 to 8000 RPM and compares torque performance across a broad operational range.

Both systems exhibit relatively similar torque values at lower engine speeds (3000–3500 RPM). At 3000 RPM, the standard exhaust slightly outperforms the PCCS (8.37 Nm vs. 8.13 Nm), but this trend quickly reverses at 3500 RPM, where the PCCS produces 9.11 Nm compared to 8.24 Nm for the standard exhaust. From this point forward, the PCCS demonstrates a significant advantage. At 4000 RPM, torque from the PCCS rises sharply to 10.98 Nm, whereas the standard system remains nearly constant at 8.39 Nm. The PCCS reaches its peak torque of 12.23 Nm at 4500 RPM, substantially higher than the standard exhaust's 8.34 Nm at the same engine speed.

Beyond 4500 RPM, torque values for the PCCS gradually decline, but they remain consistently higher than those of the standard exhaust until approximately 6000 RPM. Interestingly, at 6000 RPM, the standard exhaust briefly surpasses the PCCS, generating 9.15 Nm versus 8.68 Nm. This point marks the only RPM where the standard system exhibits superior performance. However, after 6000 RPM, both systems show a decreasing torque trend. By 8000 RPM, the torque values of both systems converge at 6.36 Nm.

The PCCS exhaust system significantly enhances engine torque, particularly within the mid-range RPMs (4000–5500 RPM), which is critical for real-world vehicle operation. The improved torque characteristics can be attributed to the PCCS design, which optimizes exhaust gas flow, reduces backpressure, and promotes better combustion efficiency. These results suggest that PCCS has strong potential to improve engine performance, fuel efficiency, and driving comfort.

Figure 12 presents a comparative analysis of power output as a function of engine speed for two exhaust system configurations: the standard exhaust and the PCCS. The evaluation covers engine speeds ranging from 3000 to 8000 RPM and highlights the performance differences between systems across various operational regimes.

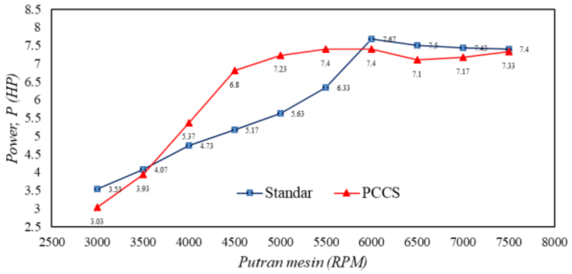

Figure 12. Graph of engine rotation speed against standard exhaust power and PCCS

The standard exhaust demonstrates a modest power advantage at the lower engine speeds (3000–3500 RPM), producing 3.53 HP at 3000 RPM compared to 3.03 HP for PCCS. However, from 3500 RPM onwards, the PCCS outperforms the standard exhaust. A notable increase is observed at 4000 RPM, where PCCS reaches 5.37 HP versus 4.73 HP from the standard configuration. This upward trend continues sharply, with the PCCS delivering 6.80 HP at 4500 RPM and 7.23 HP at 5000 RPM, significantly surpassing the corresponding values from the standard exhaust (5.63 HP at 5000 RPM).

Both systems exhibit their peak performance in the mid-range RPM zone. The PCCS plateaus at approximately 7.40 HP between 5500 and 6000 RPM, while the standard exhaust reaches a slightly higher peak of 7.67 HP at 6000 RPM. Interestingly, although the PCCS initially leads in power development, the standard exhaust briefly overtakes it at high mid-range speeds. From 6500 RPM onward, both systems show minimal variation in power output. The standard exhaust maintains relatively stable power between 7.50 HP and 7.40 HP up to 8000 RPM, whereas the PCCS shows a slight dip to 7.10 HP at 6500 RPM, gradually climbing to 7.33 HP at 8000 RPM.

The PCCS exhaust system delivers superior power output at lower to mid-range engine speeds (3500–5500 RPM), suggesting enhanced combustion efficiency and improved exhaust flow characteristics due to its conical perforated structure. However, at higher engine speeds (above 6000 RPM), the standard exhaust matches or slightly surpasses PCCS in terms of maximum power, likely due to differences in backpressure dynamics. Overall, the PCCS system offers significant torque and early power development benefits, which are particularly advantageous for applications requiring rapid acceleration and responsiveness at moderate RPM levels.

CONCLUSIONS

Implementing PCCS exhaust on a 110 cc automatic motorcycle notably influences exhaust emissions, noise levels, and engine performance. This enhancement in performance is due to the PCCS's capability to optimize exhaust flow and minimize backpressure, leading to improved combustion efficiency. The PCCS exhaust offers strong potential for improving engine performance, environmental friendliness, and rider comfort in small-capacity motorcycles.

others.

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