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Optimization Study of Diameter, Length, Filter Hole, and Engine Speed in Modified Exhaust on Power and Noise Level of 110 cc Motorcycle

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ABSTRACT

The muffler functions to reduce noise. Changes in the muffler design can also affect engine performance and the environmental impact due to noise. In densely populated urban environments, the high noise level from motor vehicles can disturb the surrounding community. The purpose of this study are as follows: 1) To understand the influence of changes in muffler diameter, pipe length, and filter hole on power. 2) To understand the influence of changes in muffler diameter, pipe length, and filter hole on noise levels. 3) To determine the optimal values obtained from changes in muffler diameter, pipe length, and filter hole diameter. The study method is a two-stage experiment. The first stage aims to determine pressure values and flow velocities to identify the optimal values for muffler design. The second stage aims to determine power and noise levels to assess the effects of the muffler design changes.Based on the conducted study, there are effects from changes in muffler diameter, pipe length, and filter hole diameter on the generated engine power. The highest power output was obtained at the variable of 50 mm muffler diameter, 425 mm pipe length, and 2 mm filter hole diameter. As for the impact on noise levels, the lowest noise level was recorded at the variable of 38 mm muffler diameter, 525 mm pipe length, and 2 mm filter hole diameter. The optimal values were obtained through muffler design changes with a diameter of 45 mm, pipe length of 475 mm, and a 2 mm filter hole diameter.

Keywords: Design, Noise, Power, Pressure, Velocity

1. INTRODUCTION

The exhaust system is an essential component in motor vehicles, including the commonly used 110 CC motorcycles by the community. The exhaust system plays a crucial role in controlling the noise produced by the internal combustion engine. While the exhaust system functions to reduce noise, changes in its design can also impact engine performance and environmental consequences due to noise emissions. In densely populated urban environments, the noise levels from motorized vehicles can cause disturbances to the surrounding community. Elevated noise levels can disrupt comfort and even have adverse effects on human hearing health.

Exhaust systems come in various designs with differing exhaust gas flow systems, which will affect the level of sound attenuation (noise) and the value of back pressure in the exhaust gases. These factors, in turn, influence engine performance, such as the generated power [1] .

The presence of significant influence of exhaust pipe type on engine performance has been revealed, with modified exhaust pipes capable of producing optimal power and torque [2], [3]. Furthermore, there is an in-depth insight into how changes in exhaust pipe design can contribute to the enhancement of power, torque, and reduction in noise levels in a 390cc motorbike [4], [5]. Subsequently, there are findings that provide valuable perspectives regarding the importance of exhaust pipe design and placement in effectively reducing noise levels [6], [7].

2. RESEARCH SIGNIFICANCE

The significance of this study resides in understanding the impact of varying levels of exhaust pipe diameter, pipe length, and filter hole diameter from previous studies on engine power and generated noise levels. By introducing incremental changes to each variable compared to the parameters of the previous research, this study aims to provide insights to the society regarding their effects and the optimal outcomes resulting from the modifications to these variables in terms of power and noise levels

3. RESEARCH METHODS

3.1 Research Theoritical

A Internal Combustion Engine (ICE) is a tool for creating motion by converting chemical energy into heat and then into translational and rotational motion, or what is called mechanical energy. ICE have three main parts, namely the cylinder head, the cylinder block, and the crankcase. Within the cylinder block, there is a combustion chamber where the combustion process takes place, converting chemical energy (fuel mixture) into mechanical energy that drives the piston to generate rotational energy on the crankshaft axis [8], [9].

An exhaust system is a component employed to reduce noise and is typically affixed to automobiles. The structure of an exhaust system includes a noise-dissipating tube referred to as a silencer. Beyond minimizing sound levels, the exhaust system in vehicles functions to guide the combustion engine's exhaust gases and stabilize its operation within the surrounding environment. In practical scenarios, a diverse range of exhaust system configurations exists, tailored to the specific engine needs of vehicles to attain optimal performance (power) [10], [11].

Noise or noise pollution can be defined as undesired sounds that can lead to discomfort for listeners. Noise can be interpreted as unwanted sounds originating from natural activities such as speech, as well as artificial activities like the use of engines [12], [13]. Noise can be defined as all undesirable sounds originating from production or work processes that can lead to hearing disturbances[14], [15] Noise is an unwanted sound from activities or actions at certain levels and times that can lead to human health disturbances and environmental discomfort [16], [17]. ICE also play a significant role in noise generation. Engine noise falls under the category of aerodynamic noise due to the airflow and noise produced by various working engine components, including the intake system, combustion process, and exhaust system of combustion gases. In the exhaust system, a muffler is provided to attenuate the generated noise [18], [19].

Noise will increase proportionally with an increase in diameter. The increase in noise is influenced by the density of the medium, which plays a role in propagating sound waves. When the medium is denser, the speed of sound propagation becomes slower. Conversely, if the medium is less dense, the speed of sound propagation increases[20]. An increase in noise will occur when using a muffler with a larger diameter than the standard. This is because the larger the muffler diameter, the higher the resulting sound or noise level [21], [22].

Another factor that affects noise level is the length of the muffler pipe. This can influence that a longer muffler pipe results in a lower level of generated noise[23], [24]. The diameter of the holes in the muffler screen also affects the generated noise level. In several variations of hole diameters, even the smallest changes in hole diameter have an impact on the sound character emitted by the engine. A smaller diameter of the holes in the silencer leads to a reduction in the noise level originating from the engine[25].

Power is the amount of work a machine performs within a specific time frame. The mechanical power generated by an engine originates from the heat energy resulting from the combustion of a fuel-air mixture [26], [27].

Power can increase with the expansion of the muffler diameter. This increase in power is linked to smoother exhaust gas flow, where a smoother flow contributes to reducing back pressure. Back pressure plays a crucial role in engine efficiency, as smoother exhaust gas flow reduces the likelihood of exhaust gas reversion within the combustion chamber. This allows exhaust gas to mix more efficiently with the fuel-air mixture from the carburetor. As a result, the combustion process becomes more optimal [28], [29].

In addition to muffler diameter affecting power, the length of the muffler pipe can also impact power. Lengthening the pipe can increase power at high engine revolutions, but it might lead to decreased performance at low to medium revolutions. Conversely, using a shorter pipe can enhance power at low and medium revolutions but might compromise performance at high revolutions[30].

Power can also be influenced by changes in the diameter of the muffler screen holes. Variations in hole diameter can affect power generation, where smaller hole diameters lead to increased power output. Conversely, larger hole diameters may result in decreased power output [31].

Back pressure is the pressure caused by the resistance experienced by exhaust gases during their expulsion, causing them to rebound from the exhaust system back towards the cylinder. The hindered exhaust gases get trapped within the cylinder due to valve overlapping, leading to a mixture of these gases with the incoming air-fuel mixture during the intake stroke [32].

Bernoulli's principle states that when a fluid moves at a higher velocity, it results in lower pressure, and conversely, when a fluid moves at a lower velocity, it generates higher pressure. This concept forms the foundation for understanding the relationship between fluid flow velocity and pressure distribution within a system [33]. The equation of Bernoulli's principle is as follows:

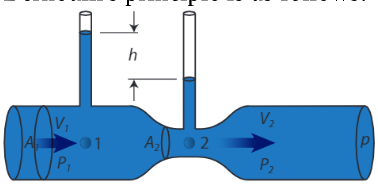

Fig 1. Bernoulli's principle

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

3.2 Data Collection Methods

The data collection method was conducted to gather data from power and noise level tests. Prior to data collection, several preparation stages were necessary. The preparation stages are as follows:

1) Ensuring that the tools and materials to be tested are in good condition.
2) Installing all the tools and materials used, such as attaching the exhaust pipe to be tested and lifting the motorcycle used in the study onto the dyno test platform. Installing the necessary equipment for the dyno test and placing the decibel meter with the distance from the edge of the muffler is approximately ± 50 cm at a slope angle of 45°.

Fig 2. Decibel meter installation

3) Once the tools and materials are securely in place, the testing is ready to be conducted.

4) If the testing has been completed and the required data has been obtained, it is necessary to replace the exhaust pipe with a different design and then perform the testing again. After all the exhaust pipe designs have been tested and the required data has been collected, the next step is the data processing and conclusion drawing process.

3.3 Data Analysis Methods

Data processing and analysis are used to analyze the effects of various muffler designs and determine optimal values based on power and noise level parameters. The complete method for data processing and analysis in the first stage is as follows:

1) The obtained data is inputted into tables for power and noise level data processing.
2) The processed data then undergoes statistical analysis. In the initial stage of statistical analysis, Design of Experiments is applied using the Taguchi method.
3) Parameters observed from the statistical analysis include Analysis of Variance and Main Effects Plot for Means, aimed at finding the optimal values.

4. RESULTS AND DISCUSSION

The subject of this discussion will be explained regarding the influence of various exhaust designs on the power and noise levels produced. In this discussion, statistical analysis of the Design of Experiment with the Taguchi method is used.

4.1 Power

The first subject is a discussion of the influence of various exhaust designs on power. This power discussion is presented in graphical form with reference to the exhaust diameter in order to make it easier to understand the data processing table. As well as an analysis to find and validate the highest engine power. From the power chart for the three variations of exhaust diameter above, it can be seen that the highest increase in power is obtained with variations of exhaust diameter of 50 mm, with a pipe length of 425 mm, and with a filter hole diameter of 2 mm with a maximum power value of 11,5 hp at 9000 rpm. However, a significant increase in power remains at 7000 rpm due to an increase in power of 3,24 hp from the previous engine speed.

After analyzing the power graph, it is necessary to carry out a statistical analysis to answer the research hypothesis. Statistical analysis of Design of Experiments (DOE) using the Taguchi method was used to answer the hypothesis of the effect of exhaust design variations on power. Below are the results of the DOE statistical analysis of the Taguchi method using the Minitab 19 application.

Table 1. ANOVA on Power

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muffler Diameter	2	0.517480	0.517480	0.258740	762.39	0.000
Long pipe	2	0.288181	0.288181	0.144091	424.57	0.000
Sieve Hole	2	0.026263	0.026263	0.013131	38.69	0.000
Muffler Diameter*Pipe Length	4	0.007963	0.007963	0.001991	5.87	0.017
Diameter of Muffler*Hole Filter	4	0.001214	0.001214	0.000304	0.89	0.510
Pipe Length*Strainer Hole	4	0.000959	0.000959	0.000240	0.71	0.610
Residual Errors	8	0.002715	0.002715	0.000339		
Total	26	0.844774				

In the table 1, the factor (Source) shows a significant influence on the test results. The Muffler Diameter Factor shows a significant effect with a DF value of 2; Seq SS and Adj SS have the same value, namely 0,517480; Adj MS has a value of 0,258740; F-Value is 762,39; The P-Value is 0,000. Then, the Pipe Length factor also shows a significant influence from the test results where the P-Value of this factor is 0,000.

Likewise, the Sieve Hole factor has a significant influence on the test results where the P-Value of this factor is 0.000. But in the three interactions between factors, only the interaction between Muffler Diameter and Pipe Length has a P-Value of 0,017 where $\alpha \leq 0{,}05$; So that only the interaction between Muffler Diameter and Pipe Length has a significant effect on the test results.

In the table 1, it was concluded that all factors or independent variables in this study had a significant influence on the test results. However, only the interaction between Muffler Diameter and Pipe Length has a significant effect on the test results.

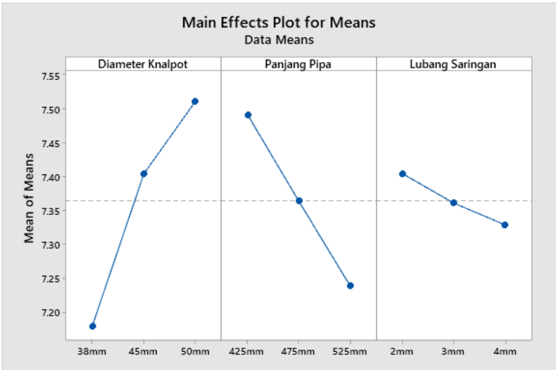

Fig 3. Main Effects Plots for Means on Power

The Main Effects Plot for Means graph in the Design of Experiments Taguchi method is used to give an overview of the effect of the independent variables on the research results. The graph above can also be used as a conclusion for the tests carried out.

Table 2. Main Effects Plot for Means on Power

Level(MD/PL/FH)	Muffler Diameter	Pipe Length	Filter Hole
1(38mm/425mm/2mm)	7,179	7,492	7,405
2(45mm/475mm/3mm)	7,404	7,364	7,361
3(50mm/525mm/4mm)	7,511	7,239	7,328
Delta	0.332	0.253	0.076
rank	1	2	3

Description: MD (Muffler Diameter); PL (Pipe Length); FH (Filter Hole)

Table 2 is the result of reading the Main Effects Plot for Means chart. The table contains values corresponding to the points on the chart. It can be seen in the graphs and tables, that the best average power is produced on the Exhaust Diameter variable with a diameter of 50 mm with a value of 7,511; Pipe length 425 mm with a value of 7,492; Filter hole 2 mm with a value of 7,405.

4.2 Noise Level

The second subject is a discussion of the influence of various exhaust designs on power. This discussion of noise levels is presented in graphical form with reference to the diameter of the muffler in order to make it easier to understand the data processing table. As well as an analysis to find and validate the lowest noise level. From noise level chart for the three variations of exhaust diameter above, it can be seen that the lowest noise level is obtained for variations of exhaust diameter of 38 mm, with a pipe length of 425 mm, and with a filter hole diameter of 2 mm with a noise value of 116,9 dB at 9000 rpm. as well as a significant increase in noise remains at 9000 rpm due to a ± 27 dB increase in noise from the previous engine speed.

After analyzing the noise level graph, it is necessary to carry out a statistical analysis to answer the research hypothesis. Statistical analysis of Design of Experiments (DOE) using the Taguchi method was used to answer the hypothesis of the effect of variations in exhaust design on noise levels. Below are the results of the DOE statistical analysis of the Taguchi method using the Minitab 19 application.

Table 3. ANOVA on Noise Level

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Muffler Diameter	2	124,698	124,698	62.3490	6254.20	0.000
Long pipe	2	15,774	15,774	7.8868	791.12	0.000
Sieve Hole	2	1,743	1,743	0.8715	87.42	0.000
Muffler Diameter*Pipe Length	4	0.200	0.200	0.0499	5.00	0.026
Diameter of Muffler*Hole Filter	4	0.009	0.009	0.0023	0.24	0911
Pipe Length*Strainer Hole	4	0.011	0.011	0.0027	0.27	0.888
Residual Errors	8	0.080	0.080	0.0100		
Total	26	142,514				

In the table 3, the factor (Source) shows a significant influence on the test results. The Muffler Diameter Factor shows a significant effect with a DF value of 2; Seq SS and Adj SS have the same value, namely 124,698; Adj MS has a value of 62,3490; F-Value is 6254,20; The P-Value is 0,000. Then, the Pipe Length factor also shows a significant influence from the test results where the P-Value of this factor is 0,000.

Likewise, the Sieve Hole factor has a significant influence on the test results where the P-Value of this factor is 0,000. But in the three interactions between factors, only the interaction between Muffler Diameter and Pipe Length has a P-Value of 0,026 where α ≤ 0,05; So that only the interaction between Muffler Diameter and Pipe Length has a significant effect on the test results.

In the table 3, it was concluded that all factors or independent variables in this study had a significant influence on the test results. However, only the interaction between Muffler Diameter and Pipe Length has a significant effect on the test results.

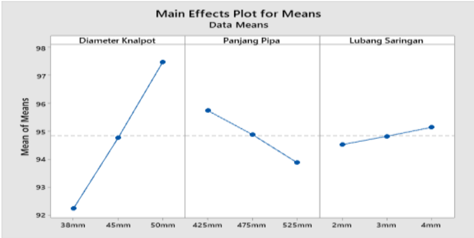

Fig 4. Main Effects Plots for Means on Noise Level

The Main Effects Plot for Means graph in the Design of Experiments Taguchi method in the fig. 4 is used to give an overview of the effect of the independent variables on the research results. The graph above can also be used as a conclusion for the tests carried out.

Table 4. Main Effects Plot for Means on Noise Level

Level(MD/PL/FH)	Muffler Diameter	Pipe Length	Filter Hole
1(38mm/425mm/2mm)	92.23	95.74	94.52
2(45mm/475mm/3mm)	94.76	94.87	94.82
3(50mm/525mm/4mm)	97.49	93.87	95.14
Delta	5.26	1.87	0.62
rank	1	2	3

Description: MD (Muffler Diameter); PL (Pipe Length); FH (Filter Hole)

Table 4 is the result of reading the Main Effects Plot for Means chart. The table contains values corresponding to the points on the chart. It can be seen in the graphs and tables, that the lowest average noise level is produced in the Muffler Diameter variable with a diameter of 38 mm with a value of 92,23; Pipe length 525 mm with a value of 93,87; Filter hole 2 mm with a value of 94,52.

From the analysis of the Main Effects Plot for Means graph on the Taguchi Design of Experiments method above, it can be concluded that the statement regarding the effect of a modified exhaust design with the smallest exhaust diameter (38 mm), the longest pipe length (525 mm), and the smallest filter hole (2 mm) on the lowest possible noise level has proven true.

However, if the noise level is low, it will be directly proportional to the power generated so that the power will be of low value. So the results of the optimal value so that the power and noise levels match, can be reviewed at the Main Effects Plot for Mean graph for power and noise levels. It can be concluded that the two graphs have similarities in the median (middle value) so that the optimal value of power and appropriate noise level lies in the exhaust diameter of 45 mm, the length of the pipe is 475 mm, and the filter hole is 3 mm.

5. CONCLUSIONS

From the conducted study, it is evident that changes in muffler diameter, pipe length, and filter hole diameter have an impact on the generated engine power. The highest power was obtained with a muffler diameter of 50 mm, pipe length of 425 mm, and a screen hole diameter of 2 mm.

Based on the conducted study, alterations in muffler diameter, pipe length, and filter hole diameter influence the level of generated noise. The lowest noise level was observed in variations with a muffler diameter of 38 mm, pipe length of 525 mm, and a screen hole diameter of 2 mm. Optimal values emerged from various diameter, pipe length, and filter hole diameter variations to produce suitable pressure and flow velocity for optimal power and noise levels. The optimal values were obtained with a muffler diameter of 45 mm, pipe length of 475 mm, and a filter hole diameter of 2 mm.

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7. AUTHOR CONTRIBUTIONS

- Conceptualization: Sugeng Hadi Susilo, Muhammad Zulfikar Rizky Anantya, Hazlina Md Yusof.
- Data curation: Muhammad Zulfikar Rizky Anantya, Hazlina Md Yusof.
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- Funding acquisition: Hazlina Md Yusof.
- Investigation: Sugeng Hadi Susilo, Muhammad Zulfikar Rizky Anantya.
- Methodology: Muhammad Zulfikar Rizky Anantya.
- Project administration: Hazlina Md Yusof.
- Resources: Sugeng Hadi Susilo.
- Software: Muhammad Zulfikar Rizky Anantya.
- Supervision: Sugeng Hadi Susilo, Muhammad Zulfikar Rizky Anantya.
- Validation: Hazlina Md Yusof.
- Visualization: Muhammad Zulfikar Rizky Anantya, Hazlina Md Yusof.
- Writing – original draft: Muhammad Zulfikar Rizky Anantya, Hazlina Md Yusof.
- Writing – review & editing: Muhammad Zulfikar Rizky Anantya, Hazlina Md Yusof.

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