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Research Article

Analysis of Boosting Engine Torque and Horsepower via Diffuser Installation on the Exhaust Pipe

Ummi Kultsum[1,*], Sartono Putro[1]
[1,*] *Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Surakarta, **Indonesia***

Corresponding author: *uk356@ums.ac.id*

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ABSTRACT

The overlapping phase occurs in Internal Combustion Engine (ICE) when performing a work cycle when the intake and exhaust valves on the cylinder are open simultaneously. The overlapping stage on the engine has benefits such as cleaning the combustion chamber and lowering its temperature before continuing its working cycle. However, overlapping also has disadvantages. When both intake and exhaust valves open simultaneously, there is a risk that fresh gas mixtures are also wasted through the exhaust, which then results in decreased engine performance. Therefore, in this research, an experiment will be carried out to improve the performance of the ICE by reducing the level of fresh gas mixtures wasted during overlapping using a Diffuser. A diffuser is a tool that s reduces the flow velocity and increases the pressure of a fluid, which in this study is the exhaust gas flow. This research was conducted with a Dynotest using a dynamometer to measure engine performance in Torque and Power on a four-stroke Yamaha Vixion 150 motorcycle ICE engine. The diffusers used in this research are a ring made of aluminium material with varying angles, namely 40°, 50°, and 60°. Then the ring is attached to the exhaust pipe to analyze the changes in torque and power performance of each diffuser. The results show highest Torque and Power produced was when the exhaust was paired with a 50° Diffuser at 6199 rpm with a Torque of 15.43 Nm and a Power of 13.5 HP. However, when the rotation is higher, the most outstanding Torque and Power is produced by the Diffuser 40°, which is 4.05 Nm and 5.8 HP at 10250 RPM rotation. With these results, achieving the highest Torque and Power depends on the Diffuser angle and the engine speed.

ABSTRAK

Pada saat Internal Combustion Engine (ICE) melakukan langkah kerja, terdapat fase overlapping, yaitu ketika katup

Kata Kunci: Performa Mesin, Diffuser, Overlap, Torsi, Daya

intake dan exhaust pada silinder terbuka disaat yang bersamaan. Overlapping pada mesin memiliki manfaat seperti membersihkan ruang bakar mesin dan menurunkan temperaturnya sebelum melanjutkan siklus kerjanya. Namun demikian, overlapping juga memiliki kelemahan. Ketika kedua katup intake dan exhaust terbuka secara bersamaan, terdapat resiko gas segar juga ikut terbuang melalui exhaust, yang kemudian berakibat pada menurunnya performa mesin. Maka dari itu, dalam penelitian ini akan dilakukan percobaan untuk meningkatkan performa ICE tersebut dengan cara mengurangi tingkat gas segar yang ikut terbuang pada saat overlapping menggunakan Diffuser. Diffuser sendiri merupakan alat yang berfungsi untuk mengurangi kecepatan aliran dan meningkatkan tekanan suatu fluida, yang dalam penelitian ini fluida tersebut adalah aliran gas exhaust. Penelitian ini dilakukan dengan Dynotest menggunakan dynamometer untuk mengukur performa mesin berupa Torsi dan Daya, dan sepeda motor empat langkah Yamaha Vixion 150. Diffuser yang digunakan adalah sebuah Ring yang terbuat dari material Aluminium dengan sudut bervariasi yaitu 40°, 50°, dan 60°, yang selanjutnya Ring dipasangkan di pia knalpot untuk dianalisis perubahan performa Torsi dan Daya dari masing – masing Diffuser. Hasil penelitian menunjukkan bahwa Torsi dan Daya tertinggi yang dihasilkan adalah ketika knalpot dipasangkan Diffuser 50° pada putaran 6199 rpm dengan Torsi 15.43 Nm dan Daya 13.5 HP. Namun ketika putaran semakin tinggi, Torsi dan Daya terbesar dihasilkan oleh Diffuser 40° yaitu 4.05 Nm dan 5.8 HP pada putaran 10250 RPM. Dengan hasil tersebut, pencapaian Torsi dan Daya tertinggi bukan saja tergantung pada sudut Diffuser, akan tetapi juga besar putaran mesin.

1. INTRODUCTION

Public use of ICE-powered automobiles is still prevalent. Based on the most recent statistics collected by *Badan Pusat Statistik* (BPS) [1], the number of motorcycles in Indonesia reached 115,023,039 units between 2018 and 2020, the second highest number behind passenger automobiles with 15,797,780 units. Despite the fact that fossil – fueled vehicles have lately begun to be replaced by electric vehicles in an effort to minimize emissions and prevent climate change due to global warming [2, 3], as long as ICE exist, innovations are still necessary to do to improve their performance. Improving ICE performance can be accomplished in a variety of ways, including boosting engine torque and power output. Torque is a measurement of the engine's ability to move the vehicle from its idle position. The lower the engine speed required to get high torque, the easier it is to move the vehicle [4, 5]. While the machine's power affects the machine's ability to perform work cycles [6, 7].

During the work stroke cycle of an ICE, there is a phase known as the overlapping phase, which occurs when both the intake valve and the engine exhaust valve are open at the same time. Before the piston reaches TDC (Top Dead Center), the intake valve opens, allowing fresh air and fuel mixture to enter combustion chamber and begin the next work cycle. Because both valves are open at the same time, there is a chance that fresh mixture may escape through the exhaust, reducing engine torque and power output [8]. Thus, a study is needed to address those drawbacks on overlapping. Various studies have been conducted addressing overlapping drawbacks on engine. Negative Valve Overlap (NVO) in Homogeneous-Charge Compression-Ignition (HCCI) engines were the subject of research by Hunicz et al. [9]. Due to the increase in surplus peak pressure as engine load rises, HCCI engines are prone to engine damage and noise throughout the combustion process. Consequently, through NVO, variable valve timing and fuel restructuring are implemented in the engine to boost the high load limit. NVO is also the topic of Ahmad et al. [10], who examined the effect of NVO in high-loading methanol- and diesel-fueled engines because to their high risk of failed ignition and tendency for high pressure increase rates. Kimura et al. [11] proceeded their research on NVO by investigating NVO in HCCI engines with modeling-based controls. In addition to studies, Efi et al. [8] conducted research on the influence of valve lift overlaps using the CFD (Computational Fluid Dynamic) simulation approach of charge flow engines with varied cam profiles.

Numerous overlapping research are conducted on heavy-duty engines, such as HCCI, according to the vast majority of the available literature. As a result, the overlapping effect on lighter duty engines, such as powered vehicles with spark plug ignition, is still uncommon and could be a new topic for improving engine performance. In this study, a diffuser was installed to the exhaust pipe to mitigate overlapping and improve engine performance. A diffuser is a device used to decrease flow velocity [12, 13]. In certain occurrences, the diffuser can improve the performance of a cycle or mechanism, such as in the research of Askari and Wisnoe [14], who found in their study on pressure drop and flow characteristics that the addition of a diffuser with semi-circular protrusions on its inner profile can increase recirculation and eddies in the interior around the dimple. McLaughlin et al. [15] found that varying a vaned diffuser with a diverging endwall concept can reduce the high-Pressure Ratio (PR) centrifugal compressors' dimensions without sacrificing performance. The compressor can also achieve exact efficiency by radially reducing up to 15 % of the diffuser passage from its initial size, resulting in a cut on its cost and weight. Based on this research, it is clear that there is a vast range of research on diffusers that still have room for development, particularly those dealing with applications on engines.

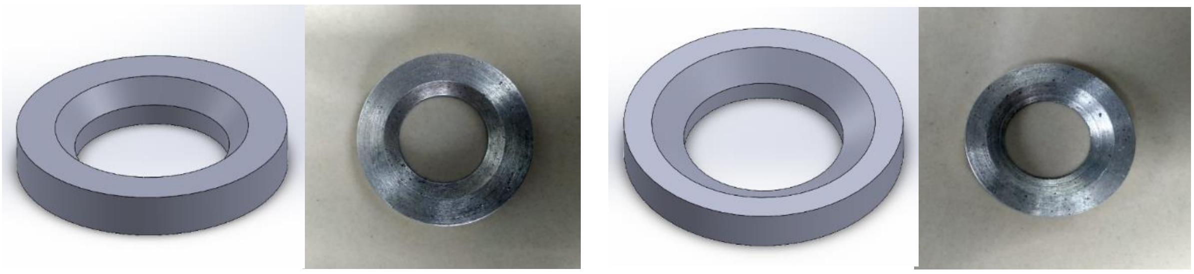
In the ICE, there is a flow of fluid during the combustion process. When overlapping happens, the fresh mixture might also flow towards the exhaust. The addition of a diffuser is expected to reduce wasted fresh mixture flow and hence improve engine performance. Therefore, a study was done to determine how adding a diffuser on a motorcycle's exhaust impacts engine performance, including torque and horsepower. As a motorcycle modification variation, the diffuser is an Aluminum ring with angles of 40°, 50°, and 60°. The diffuser ring is then installed on the exhaust pipe and its performance in terms of torque and power is evaluated using Dynotest. It is rare to come across study on the application of diffusers in ICE, and it is expected that in the future, this research can be applied to larger types of vehicles and engines.

2. RESEARCH METHOD

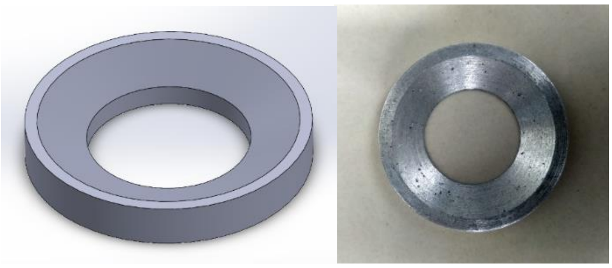
This study employed an experimental approach in the form of Dynotest testing. The Dynamometer test, or Dynotest, is a common method of measuring engine output. The Dynotest was performed at the Setiar Jaya Factory Workshop in Sukoharjo Regency, Indonesia. The Dynamometer utilized in this research Dynotest is a Chassis Dynamometer type on-wheel Dynamometer. The motorbike used to assess the performance of ICE is a Yamaha Vixion 150 four-stroke model with a manual clutch. Figure 1 displays the Dynotest setup.

Figure 1. Dynamometer and Motorcycle Setup

At each testing stage, the exhaust pipe is paired with a diffuser with three different angles, specifically 40°, 50°, and 60°. So that there are a total of four stages, with the normal motorcycle conditions and the equipped with diffuser conditions each having their own set of three diffuser angles (40°, 50°, and 60° respectively). The diffuser is an aluminum ring with identical thickness, inner diameter, and outer diameter measurements. Each diffuser ring has a 5 mm thickness, a 20 mm inner diameter, and a 35 mm outer diameter. Figure 2 (a-c) illustrates the design of each diffuser ring.



(a) (b)



(c)

Figure 2. Diffuser Ring Design and Geometry of (a) 40°, (b) 50°, and (c) 60°

The installation of a diffuser is intended to cut down on the amount of fresh mixture that is lost along with the exhaust from the motorcycle. This presumption is based in the flow continuity principle and Bernoulli's law. Equation 1 illustrates the continuity formula of the flow along the diffuser.

$$A_1.v_1 = A_2 v_2 \qquad (1)$$

Subscript 1 represents the flow of fresh mixture that is likewise discarded when overlapping from the direction of the engine, and subscript 2 represents the exhaust gas released into the atmosphere through the exhaust. At the diffuser outlet, the flow that is exiting the diffuser will suffer a decrease in velocity. This is because the diffuser outlet has a wider area than its inlet. Figure 3 demonstrates the flow pattern for the diffuser.

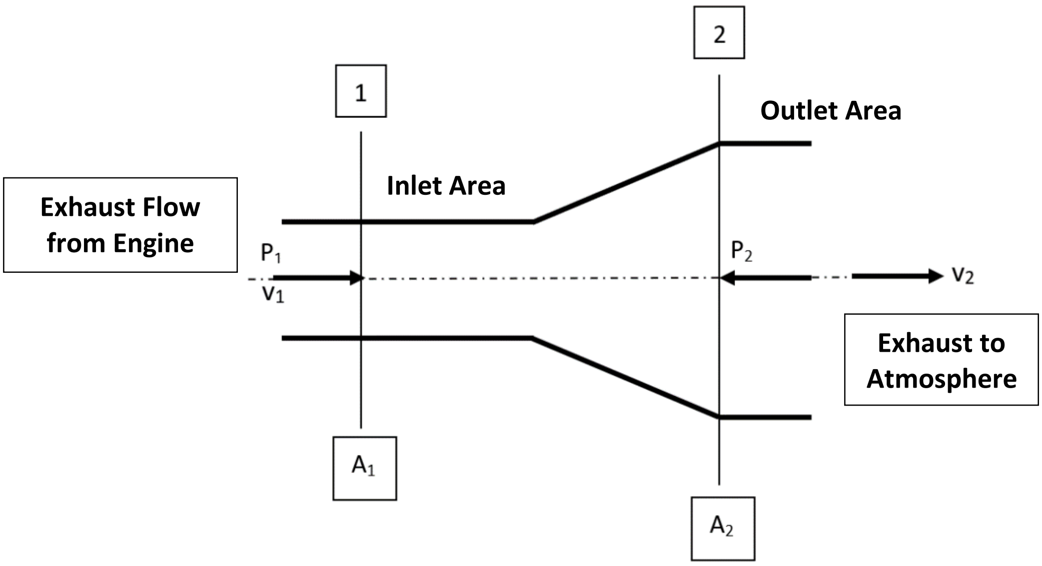


Figure 3. Flow Through Diffuser Illustration

The decrease in speed in v_2 will be followed by an increase in pressure in that area. Equation 2 demonstrates that this approach is consistent with the Bernoulli equation describing flow behavior.

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

It is assumed that density ρ, gravitational acceleration g, and height h are identical, whereas there is still some changes in the values of the flow velocity v and the pressure P. By linking the two concepts of continuity and Bernoulli, the larger the outlet area, the slower the flow v_2 and the higher the pressure at P_2. P_2 is the back pressure that is exerted toward the diffuser's input; hence, the higher the value of P_2 is, the more difficult the flow from v_1 to escape; this, in turn, can lower the amount of the fresh mixture that is released during engine overlap.
The technique used in this research to attach the Diffuser ring to the vehicle's exhaust is based on the two principles of continuity and Bernoulli's law. Figure 4 illustrates the reference position of the diffuser ring on the exhaust pipe, and Figure 5 demonstrates the direct

installation of the diffuser ring on the exhaust pipe. Each experiment is given a gap between stages to reduce the exhaust temperature after being operated.

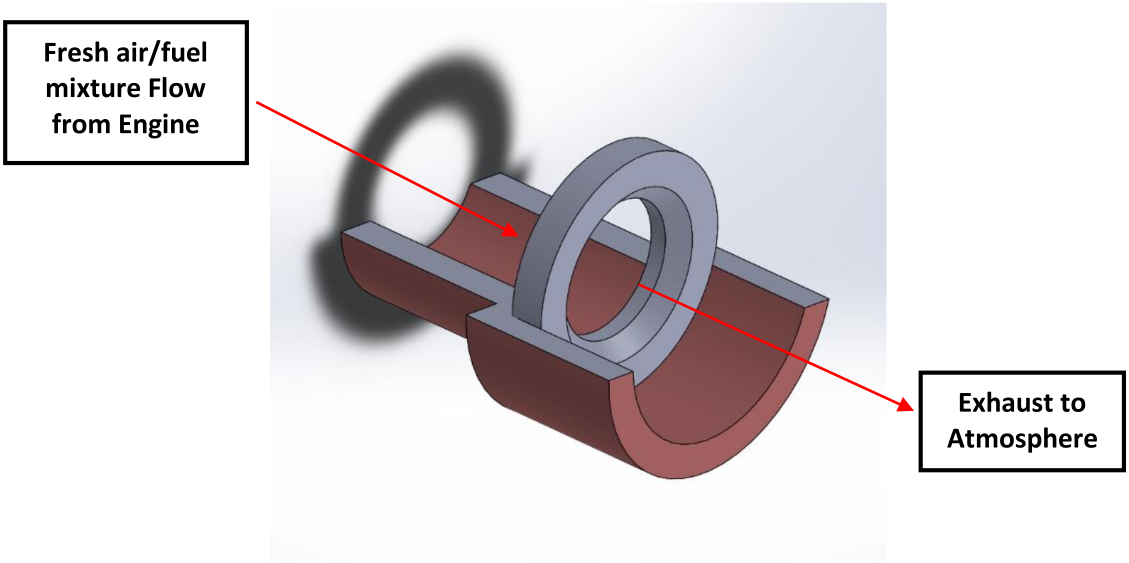


Figure 4. Illustration of the Diffuser Installation Reference in the Exhaust

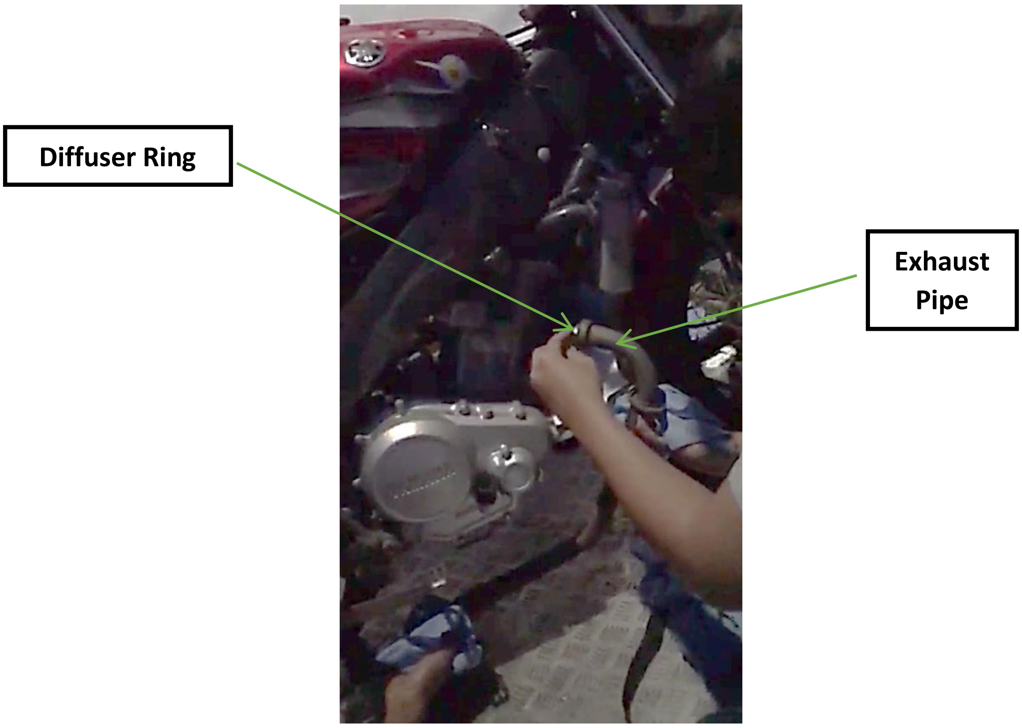


Figure 5. Direct Attaching of Diffuser Ring in Exhaust Pipe

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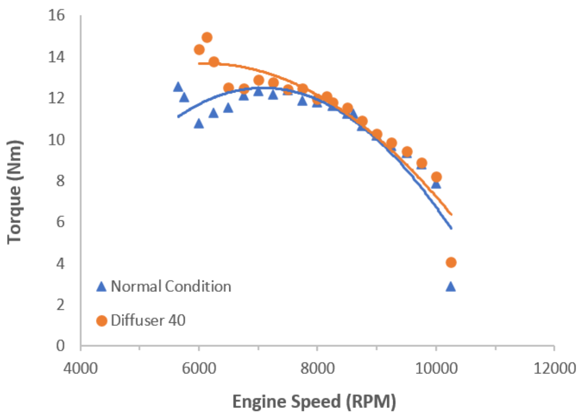
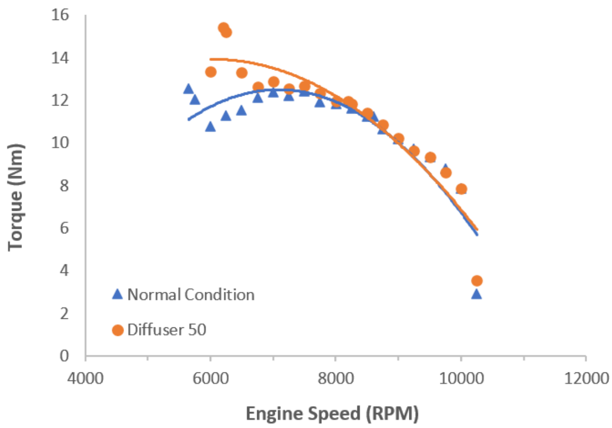
3. RESULT AND DISCUSSION

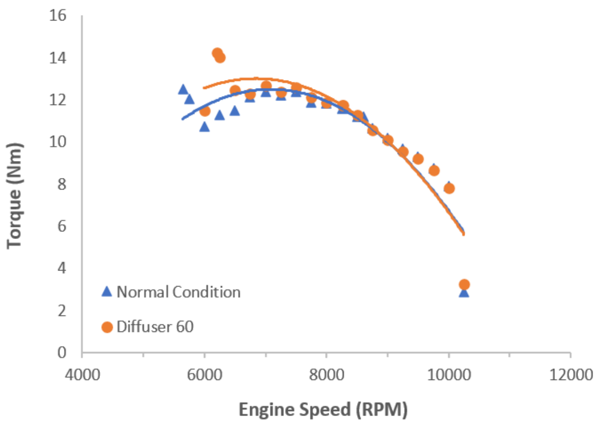
This study presents its findings in two types of data: Torque data on engine speed and Power data on engine speed. Figure 6 (a-c) depicts torque performance data comparing a motorcycle in normal condition to a motorcycle equipped with a diffuser ring on the exhaust.



(a)



(b)



(c)

Figure 6. Torque Performance Over Engine Speed Under Normal Engine Conditions and With the Installation of (a) 40°, (b) 50°, and (c) 60° Diffuser Rings.

Figure 6 (a) depicts the circumstance when a 40° diffuser ring is equipped onto an exhaust pipe. The graph shows that the engine's performance in achieving torque improves. With a 40° diffuser ring, the motorcycle gained 14.39 Nm in the lower revs at 6000 RPM. In contrast, the torque of the motorcycle under ordinary conditions was just 10.79 Nm. This rise is considerable. Improvements were also seen in two other diffusers, 50° diffuser ring in Figure 6 (b) and 60° diffuser ring in Figure 6 (c). The torque gain for the 50° diffuser ring is 13.35 Nm, while the torque gain for the 60° diffuser ring is 11.54 Nm. However, the three diffusers each have a different engine speed at which they produce their peak torque value. As a reference for these observations, Figure 7 depicts the results of a comparison of the three torques, together with standard conditions.

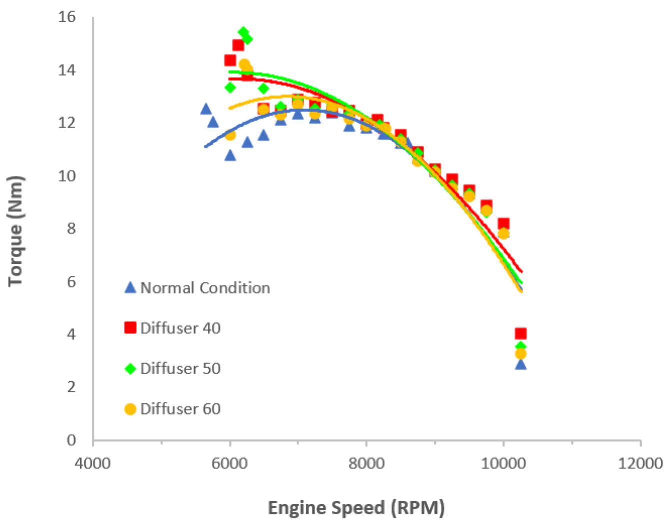
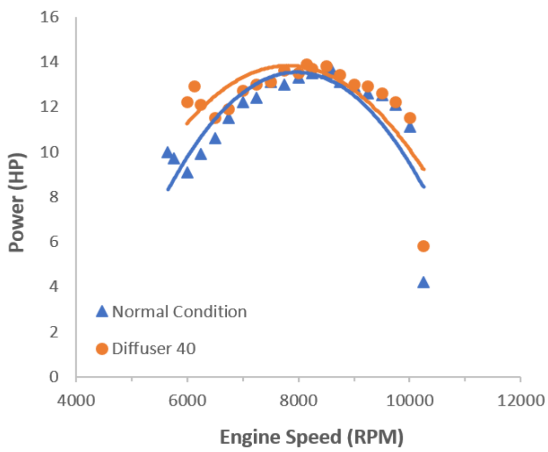


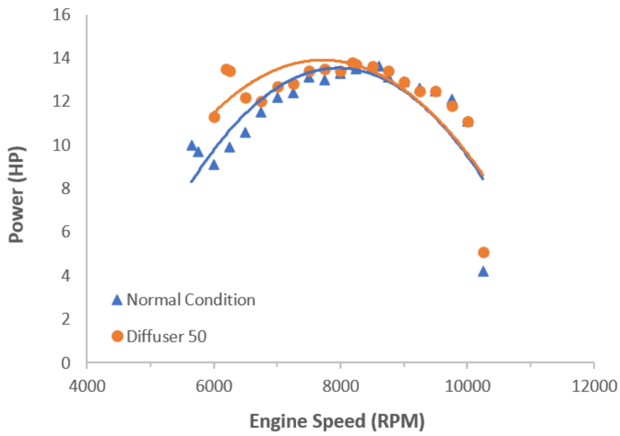
Figure 7. Comparison of Torque Performance Vs Engine Speed with And Without a Diffuser.

The maximum torque of the three diffuser ring variations is reached when the motorcycle utilizes a 50° diffuser ring, which is 15.43 Nm at 6199 RPM engine speed. When paired with a 40° diffuser ring, the maximum torque achieved is 14.95 Nm at 6126 RPM, while the maximum torque achieved when partnered with a 60° diffuser ring is 14.22 Nm at 6211 RPM. When it comes to keeping torque steady at high RPMs, however, the 40° diffuser ring excels. The 40° diffuser ring can reach 4.05 Nm at 10250 RPM, which is the highest speed of the engine. At the same revs, the diffuser with a 50° angle has a torque of 3.56 Nm, while the diffuser with a 60° angle has a torque of 3.28 Nm. In contrast, the usual conditions may only achieve 2.9 Nm of torque.

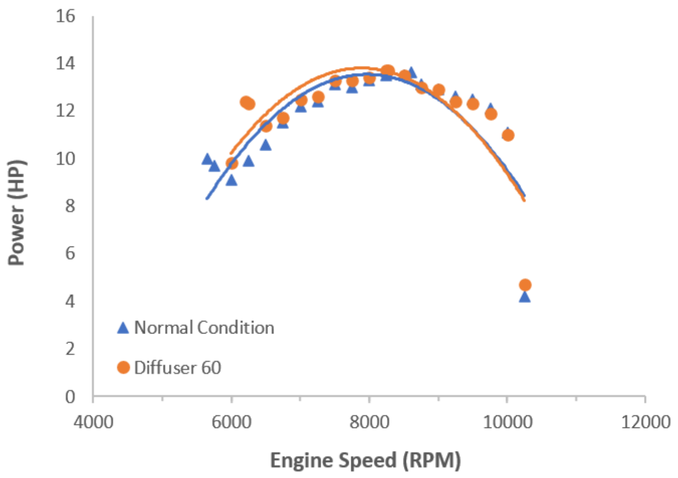
With torque performance as measured by the data, the resulting power performance is not significantly different from the torque achievement. Figure 8 illustrates the power achievement graph for each diffuser (a-c).



(a)



(b)



(c)

Figure 8. Power Performance Over Engine Speed Under Normal Engine Conditions and With the Installation of (a) 40°, (b) 50°, and (c) 60° Diffuser Rings

When comparing the power output of a conventional engine to that of one using a 40° or 50° diffuser ring, the latter produces noticeably better results. At 6000 RPM, the 40° diffuser ring produces 12.2 HP, whereas the 50° diffuser ring produces 11.3 HP. The 60° diffuser ring, on the other hand, has a contrast that isn't too different from the normal state. Its difference is 9.8 HP, while the normal state can only reach 9.1 HP.

Comparing the power accomplishments of each diffuser, the 40° diffuser is also capable of maintaining a high power as the engine speed increases. Figure 9 shows a comparison of the three diffusers used to achieve these outcomes.

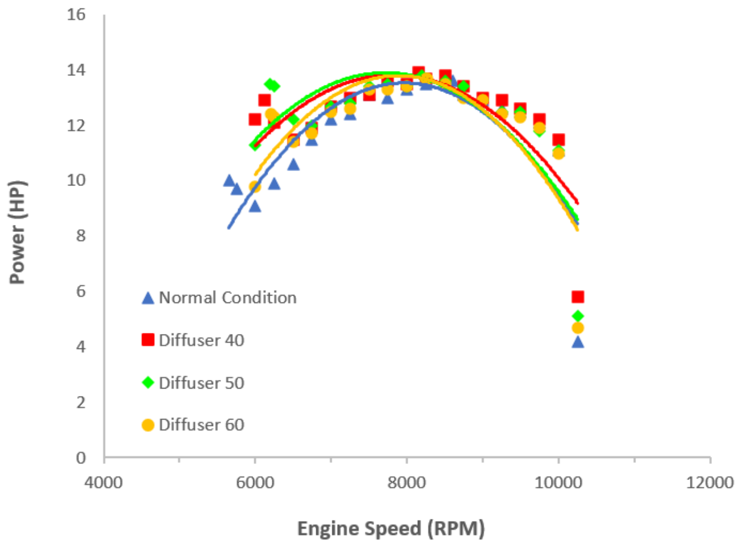


Figure 9. Comparison of Power Performance Vs Engine Speed with and Without a Diffuser

At an engine speed of 6126 RPM, a 40° diffuser ring can deliver a maximum of 12.9 HP.

The 50° diffuser ring has the maximum power of 13.5 HP at 6199 RPM, whereas 60° diffuser ring has the highest power of 12.4 HP at 6211 RPM. Consequently, a 50° diffuser ring delivers the most power. However, when engine speed increases, the 40° diffuser ring produces the most power, 5.8 HP at 10250 RPM. The 50° diffuser ring has 5.1 HP at the same revs, while the 60° diffuser ring has 4.7 HP.

On average, installing a diffuser boosts torque and power from standard motorcycle engine settings. However, the increase in torque and power produced diminishes as the degree of the diffuser angle increases. Theoretically, according to continuity and Bernoulli's equations, the larger the diffuser angle, the wider the cross-section area, and the back pressure generated from the diffuser outlet to the diffuser intake also increase, resulting in a much-reduced flow velocity. Based on this theorem, the highest Torque and Power are expected to be produced by diffuser 60. However, in this research, the diffuser installed shows the best torque and power generated are from a smaller angle diffuser. These results could be referenced to the lack of efficiency as the pressure kept building up around the diffuser outlet when the diffuser area got wider. As demonstrated in Gülmez and Özmen [16] research regarding the exhaust backpressure on a diesel engine, more backpressure build-up could negatively affect the engine performance. The same result was also demonstrated by Ma et al. [17], where backpressure causes the engine output power to drop significantly in the diesel engine.

4. CONCLUSION

From the research conducted, the Torque and Data generated from diffuser-mounted motorcycle depict improvement from normal conditions. The results show highest Torque and Power produced was when the exhaust was paired with a 50° Diffuser at 6199 rpm with a Torque of 15.43 Nm and a Power of 13.5 HP. However, when the rotation is higher, the most outstanding Torque and Power is produced by the Diffuser 40°, which is 4.05 Nm and 5.8 HP at 10250 RPM rotation. These results show that achieving the highest Torque and Power depends on the diffuser angle and the engine speed as it increases along with the load. Also, the improvements should consider the backpressure caused by a larger diffuser area and its effect on the engine, such as heat accumulation which can lead to degradation in performance.

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