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The effect of gear ratio on engine performance

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ABSTRACT:
The objective of this paper is to determine the impact of gear ratio and engine rotation on engine performance. The research was conducted experimentally with variations in gear ratios of 3.14, 3.21, and 3.00 at engine speeds ranging from 4000 to 7000 rpm. Engine performance testing was carried out on a Mandalika Desantara prototype engine using a rope brake dynamometer. The performance metrics tested include distance traveled, torque, and fuel consumption. The results show that the highest torque was achieved at an engine rotation of 6000 rpm with a gear ratio of 3.46, producing 11.00 Nm. The lowest fuel consumption was achieved at an engine rotation of 4000 rpm with a gear ratio of 3.00, measuring 0.47 kg/h, while the highest fuel consumption at 4000 rpm was observed at a gear ratio of 3.46, measuring 0.58 kg/h. The longest distance traveled was obtained at a gear ratio of 3.00, reaching 210.07 km at 7000 rpm and 223.82 km at 6000 rpm.

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I. INTRUDUCTION

An energy-efficient vehicle is a vehicle designed to use energy efficiently, resulting in lower exhaust emissions and better fuel efficiency while being designed with good safety elements [1]. Energy-efficient vehicles are often featured in national and international competitions, such as the Shell Eco-marathon. The Shell Eco-marathon is an event focused on developing innovative mobility solutions by designing, building, testing, and driving future vehicles that meet safety standards and can cover the greatest distance using minimal energy sources [2]. Engine performance is the capability of an engine to generate optimal power and torque while using fuel efficiently. The parameters of engine performance include torque, power, and fuel consumption [3]. Good engine performance enhances overall engine function, especially in terms of acceleration, speed, and responsiveness to load, while allowing for efficient fuel use.A reduction in torque and power due to a decrease in cylinder volume negatively impacts engine performance in terms of acceleration and vehicle speed. Furthermore, reduced engine torque and power lower the output power from the engine's output shaft to the rear wheels, making the vehicle harder to move due to limited torque. Low rear-wheel torque forces the engine to produce high power and revolutions to achieve sufficient torque at the rear wheels, leading to increased fuel consumption. One way to address this issue is by changing the gear ratio on the sprocket. Adjusting the gear ratio allows the engine to operate at lower revolutions, torque, and power, aiming to increase torque at the rear wheels. This reduces the engine's workload, enhancing fuel efficiency. The gear ratio is the ratio between the number of teeth connected to the main shaft (input) and the number of teeth connected to the other shaft (output). The gear ratio functions to modify power and rotational speed, as it significantly affects the torque and revolutions produced by the system. This adjustment can be made by adding or reducing the number of sprocket gear teeth, either on the front or rear gears.

The main component related to power and fuel consumption is the transmission system. The transmission system is used to transmit torque from the electric motor to the wheels. There are three types of vehicle transmission systems: automatic, manual variable, and continuously variable [4]. The continuously variable transmission (CVT) is more comfortable to use but is less efficient than automatic transmission. Multi-speed transmission systems perform better than single-speed systems in electric vehicles. However, multi-gear systems add complexity, such as optimal gear ratio selection, shift scheduling, precise shift control, torque interruption during shifting, increased mass, and transmission losses [5].Internal combustion engines (ICE), which have limited potential to improve efficiency, may still benefit from high-pressure turbocharging [6], biofuel usage, and reduction of mechanical losses [7]. Higher gear ratio values improve a vehicle's ability to handle uphill conditions and accelerate faster, while lower gear ratios help determine the maximum speed limit and reduce fuel energy consumption [8,9]. The timing of upshifts or downshifts depends on the vehicle's performance demands. Research on optimizing gear ratios and shift scheduling is important. Two primary parameters underpin this research: throttle position or torque demand and vehicle speed. Examples include studies on the effect of transmission ratio selection on electric motor vehicle performance [10], the impact of different gear ratios on EV performance with standard or fixed shift schedules [11], and the combined effect of gear ratios and shift schedules [12].

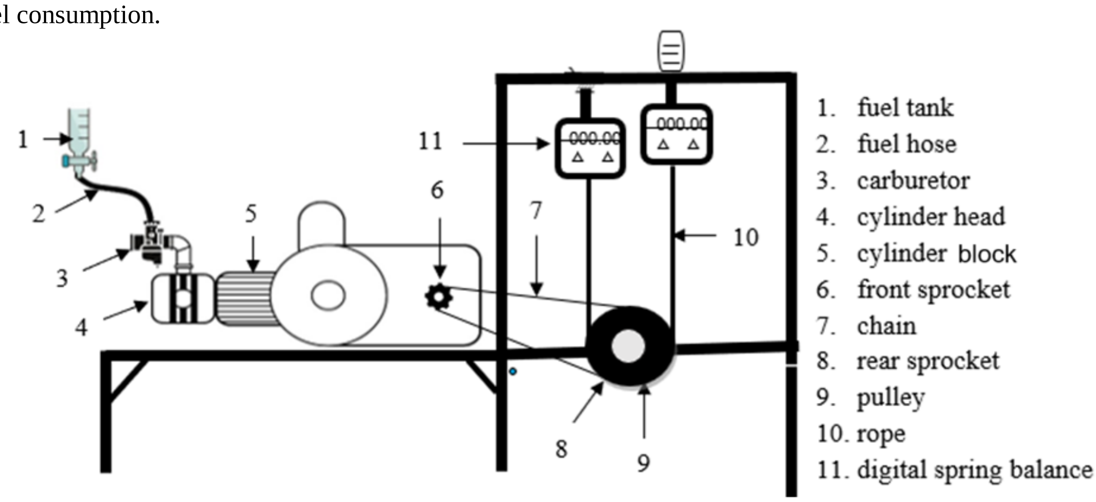
II. EXPERIMENTAL SETUP

Experimental methods are used to determine the influence of gear ratios on engine performance. The gear ratio variations used are 3.46, 3.21, and 3.00. The number of teeth on the rear sprocket is 45T, and on the front sprocket are 13T, 14T, and 15T. Engine speeds during testing are set at 4000 rpm, 5000 rpm, and 6000 rpm in 4th gear to determine the input rotation at the engine output shaft and the output rotation at the rear wheel.

(a) (b)

Figur 1. Sprocket gear a) front sprocket gear b) rear sprocket gear

The testing was conducted on an air-cooled, 4-stroke SOHC engine with a cylinder volume of 97.1 cm³ and a compression ratio of 8.8:1. A rope brake dynamometer was used as the test instrument. The tests aimed to measure torque, effective power, and fuel consumption. The rope brake dynamometer was positioned on a stand to measure the generated torque and effective power, as well as the engine's position during data collection for fuel consumption.



Figur 2. Test equipment schematic

The results of research on the influence of gear ratio and engine rotation variations on engine performance on the Mandalika Desantara prototype vehicle show the following data results.

III. RESULT AND DISCUSSION

Figure 3 shows that as engine rotation increases, the wheel's circumferential speed also rises. The highest wheel circumferential speed is achieved at an engine rotation of 7000 rpm. This is because the gear ratio used affects the wheel's circumferential speed. A smaller gear ratio results in a higher circumferential speed of the wheel, as each engine rotation is converted into more rear-wheel rotations through a smaller gear ratio. At a gear ratio of 3.00, one circumferential speed is achieved with three engine rotations. Higher engine speeds lead to higher circumferential speeds due to the impact of the gear ratio used. The increase in engine rotation from 4000 rpm to 5000 rpm, 6000 rpm, and 7000 rpm results in corresponding increases in wheel speed of 26.6%, 18.8%, and 17.7%.

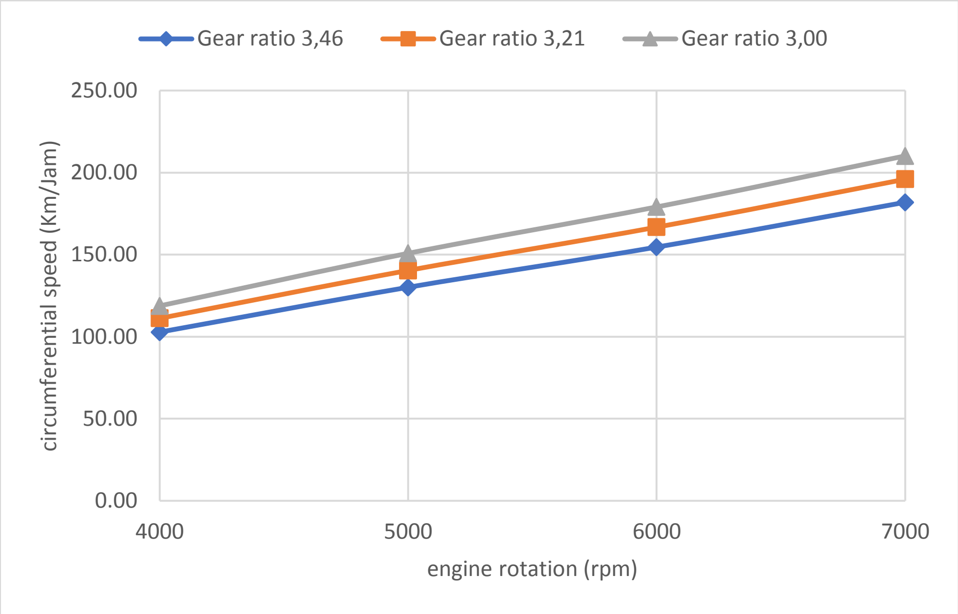


Figure 3. circumferential speed vs. Engine Rotation across Gear Ratio Variations

Figure 4, the distance achieved at different gear ratios increases with engine rotation up to around 6000 rpm (±100 rpm) and then shows a decrease in torque at 7000 rpm (±100 rpm). This indicates that the longest travel distance for each gear ratio variation occurs at 6000 rpm. Observing the different gear ratios, the increase in travel distance at each engine rotation occurs with smaller gear ratios, while decreases in travel distance at each engine rotation are observed with larger gear ratios.

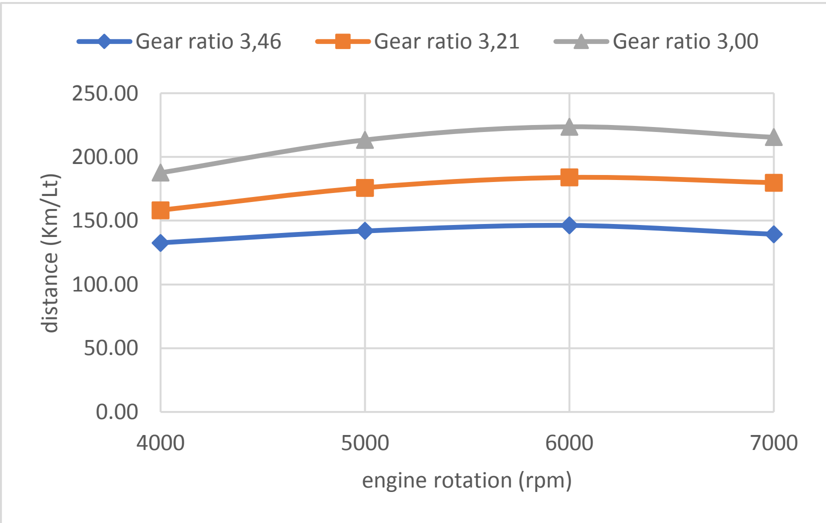


Figure 4. Distance vs. Engine Rotation across Gear Ratio Variations

The highest travel distance is obtained at a gear ratio of 3.00 with an engine rotation of 6000 rpm (±100 rpm), achieving 223.82 km/l, while the lowest travel distance at the same engine rotation is at a gear ratio of 3.46, with 146.39 km/l. This is because travel distance is influenced by wheel circumferential speed and fuel consumption, with higher wheel speed and lower fuel consumption resulting in a greater travel distance. Observing the gear ratio, it is clear that the smallest gear ratio provides the longest travel distance, as a 3.00 gear ratio can produce higher wheel circumferential speed than other variations. The higher wheel speed at a gear ratio of 3.00 is due to the difference in the number of teeth on the front and rear sprockets, where three rotations of the front sprocket produce one wheel rotation, allowing a 3.00 gear ratio to achieve a higher wheel speed than other variations. Examining engine speed, the lowest fuel consumption at each tested engine rotation is achieved at a 3.00 gear ratio, as previous tests showed that this ratio generates the highest wheel circumferential speed at lower torque and effective power, thus reducing fuel consumption. This results in the longest travel distance being achieved at a gear ratio of 3.00, as it can produce the highest wheel speed with the lowest fuel consumption compared to other variations. The 3.00 gear ratio is suitable for vehicles as it enables the longest travel distance without requiring the highest torque and effective power, thus making the engine's fuel consumption more efficient than with other gear ratios.

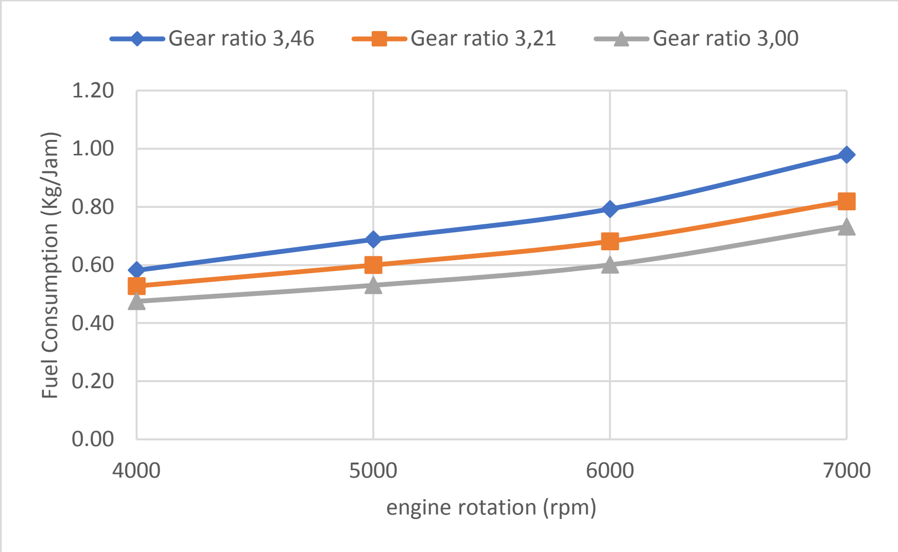


Figure 5. Fuel Consumption vs. Engine Rotation across Gear Ratio Variations

Figure 5 shows an increase in fuel consumption as engine rotation rises across different gear ratio variations. The higher the engine speed, the more fuel is consumed due to the increased number of combustion cycles. The lowest fuel consumption is achieved with a gear ratio of 3.00 at an engine rotation of 7000 rpm (±100 rpm), with a consumption of 0.78 kg/hour, while the highest fuel consumption is seen with a gear ratio of 3.46 at the same engine speed, reaching 0.98 kg/hour. This higher engine rotation lead to greater fuel consumption, as the number of combustion cycles also increases.Observing the gear ratio variations used, the 3.00 gear ratio shows more efficient fuel consumption compared to gear ratios 3.21 and 3.46. This occurs because the 3.00 gear ratio can produce high speeds at lower engine rpm, making fuel consumption significantly more efficient than with the 3.21 and 3.46 ratios. Additionally, torque and effective power testing at a 3.00 gear ratio resulted in lower torque and effective power compared to the other ratios, allowing the engine to achieve maximum speed at lower rpm without expending large amounts of energy, thus making fuel consumption more efficient.Since this vehicle is designed to compete in energy-efficiency competitions, such as those held by Shell, the optimal gear ratio to use is 3.00. The fuel consumption testing results show that the lowest fuel consumption is achieved with this ratio, reaching 0.47 kg/hour, compared to other gear ratio variations.

Figure 6. Torque vs. Engine rotation across Gear Ratio Variations

Figure 6 shows that torque increases with rising engine rotation up to 6000 rpm, after which it decreases at 7000 rpm across the different gear ratio variations. This indicates that the maximum torque for each gear ratio occurs at 6000 rpm. Observing the gear ratio variations, torque increases with larger gear ratios at each engine speed, while torque decreases at each engine rotation with smaller gear ratios. The highest maximum torque for each gear ratio occurs at 6000 rpm, with the highest torque at a 3.46 gear ratio, reaching 11.00 Nm at this engine speed. This is because the gear ratio affects the torque generated. Additionally, the tangential force at a 3.46 gear ratio is greater when tested with a rope brake dynamometer compared to the 3.21 and 3.00 gear ratios. The larger turning radius on the rear wheel also impacts the resulting torque, as torque at the rear wheel is influenced by tangential force and turning radius. The greater the tangential force and turning radius, the higher the torque generated.

IV. CONCLUSION

Variations in gear ratio and engine rotation influence torque and effective fuel consumption. The results of a two-way ANOVA statistical analysis indicate that a significant interaction occurs between variations in engine rotation and gear ratio concerning fuel consumption and distance, while no significant interaction is observed between engine rotation and gear ratio regarding torque testing. The highest average torque at the rear wheel is achieved with a gear ratio of 3.46, measuring 11.00 Nm at an engine rotation of 6000 rpm, while the lowest average torque at the rear wheel is recorded at a gear ratio of 3.00, with a value of 8.54 Nm at the same engine speed. The lowest average fuel consumption is observed with a gear ratio of 3.00, at 0.47 kg/hour at an engine rotation of 4000 rpm, whereas the highest average fuel consumption is noted with a gear ratio of 3.46, measuring 0.58 kg/hour at 4000 rpm. The longest distance is achieved with a gear ratio of 3.00, recording 223.82 km/l at an engine rotation of 6000 rpm, while the shortest distance is noted with a gear ratio of 3.46 at the same engine speed, measuring 146.39 km/l.

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