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Analysis Of The Efficiency Of Using Brushless DC Motors On Load And Speed On Electric Motorcycles

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ABSTRACT
This study examines the efficiency of electric power in BLDC motors as electric motorcycle drivers with various load and speed experiments. Electric motorcycles are one of the vehicles that are in great demand by the public. BLDC motors are the main drivers of electric motorcycles where motor capacity planning includes motor power and torque which greatly affect the acceleration and speed of the motorcycle. Motor capacity planning is obtained by calculating the total weight, the location of the motor's center of gravity, the desired acceleration, tire rolling resistance to asphalt, air resistance and road slope angle. From the calculations and analyses that have been carried out, the required motor power is 2.5 kW. Testing the motor's ability to carry loads is carried out by providing variations in passenger and goods loads of 58 kg, 98 kg and 135 kg, and driven with a target speed of 10 km / h, 20 km / h and 30 km / h.

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INTRODUCTION

Electric vehicles have emerged as a major driver of change in the modern automotive industry. Electric vehicles offer a number of significant advantages over conventional fossil fuel vehicles, particularly in terms of energy efficiency and environmental impact. One of the main advantages of electric vehicles is their higher energy efficiency. With the use of more efficient electric motors and the ability to convert electrical energy directly into motion, electric vehicles can achieve much higher levels of efficiency than internal combustion engine vehicles. The high development of electric vehicles is in line with the need for the use of Brushless DC (BLDC) electric motors which are known for their high efficiency. This motor requires a special driver to control the torque value, direction of rotation, rotation speed and acceleration and deceleration. Errors in the BLDC motor driver settings can result in decreased motor performance with symptoms of overheating, lack of power or excessive power so that it is wasteful in electricity consumption. Therefore, it is necessary to plan an electric motor that is in accordance with the load to be driven.

Research related to the design of BLDC motors has been conducted by Wahyudi Budi Pramono in 2016 with the result of obtaining a 10 kW BLDC motor with a rotation speed of 1500 rpm. The results of the study obtained the number of coils on the stator as many as 6 coils, each phase 24,192 coils and the number of phases as many as 3 phases. The physical dimensions of the stator are in the form of an arrangement of 84 mm thick plates, composed of 2 mm thick plates each. The stator coil is 94 mm thick and the final dimensions of the motor are 144 mm wide and 230 mm in outer diameter.

The efficiency of a BLDC electric motor is a core element in the design of an electric vehicle, and has a significant impact on the overall performance of the vehicle. The main characteristic that affects the performance of an electric vehicle is the energy efficiency of the BLDC electric motor. Therefore, it is necessary to conduct research on the load factor as an influence on the efficiency of the BLDC electric motor. In 2022, Ikhsan analyzed the battery capacity used to drive an electric motorbike with varying driver weights and showed that the weight of the load and speed on the motorbike affected battery usage. Then in 2023 Zain designed a two-wheeled electric vehicle and analyzed the effect of giving different load weights on the efficiency of Lithium Batteries in two-wheeled electric vehicles by considering the slope of the road and showed that tracks with steep slopes would also experience a large voltage drop. The planning of an electric motor involving mechanical components, load and speed was carried out by Hendarto Putra in 2019. This study focuses on the maximum speed generated by an electric bicycle with varying loads.

This study presents the calculation and analysis of electric motor power requirements to achieve certain acceleration and speed, taking into account load factors, tire friction conditions with the road, wind resistance and road slope angle. The specifications of the motors produced and installed were tested by riding an electric motorcycle with varying loads and speeds. Measurement of electrical power consumption was carried out to determine how effective the electrical energy used by the electric motor is converted into kinetic energy.

METHOD

The research was conducted in the following stages:

a. Collection of mechanical specification data for electric motorcycles.
b. Total motor load measurement
c. Collecting data on road characteristics, wind in the surrounding environment and determining a flat road as a test site.
d. Calculation of the traction force required by an electric motorbike
e. Electric motor power calculation
f. Testing the performance of electric motors under various load conditions and various speeds.
g. Calculation of the efficiency of electrical energy converted into kinetic energy

Electric motorcycle conversion is a motorcycle that is converted from gasoline powered to electric powered. This electric powered vehicle uses a Lithium Ion battery with a voltage of 48 V 20 Ah, a 48 V 3000 Watt Controller, a 12 V electrical system and is equipped with a Brushless DC (BLDC) motor.

Figure 1. Electric Motor Conversion Design

In conceptualizing electric vehicles, it is necessary to calculate the thrust or pull force to determine the torque and rpm values of the motor which are the considerations for which motor is chosen as the wheel drive. The following is the electric motor conversion data which is the calculation in selecting the motor:

m = mass = 100 kg + 76 kg (rider mass)
v = Maximum speed = 40 km/h or 11.11 m/s
t = acceleration time = 10 seconds
a = Acceleration = v/t = 1.11 m/s2
Cd = motorcycle with rider = 0.5
C = bicycle tire on asphalt road = 0.004
A = 1.5 m x 0.6 m
D = wheel diameter = 14 inch = 0.3556m
r = radius of the wheel = $\frac{0.3556}{2}$= 0.1778 m

On the conversion motor, the value of the degree of inclination is considered 0 (zero) because the vehicle is run on a flat road or track. According to the description above, we can calculate the value of the traction force, namely:

$$Fte = Fad + Frr + Fhc + Fla$$

Aerodynamic Style:

$$F_{ad} = \frac{1}{2} \rho A_f C_d v^2$$

Rolling resistance style:

$$F_{rr} = \mu_{rr} \ x \ m \ x \ g$$

Hill climb style:
F_{hc}= W sin θ
Acceleration Force:
$Fla = m$xa

To ensure the required drive motor capacity is in accordance with the system specifications, the determination of motor power can be calculated using the equation:

$$P = F_{te} \ x \ v$$

The results obtained to determine and find out the effect of load on the current output and speed of the BLDC motor on the conversion motorcycle. Some variables that will be tested in this study include variations in load values, namely 58 kg, 95 kg, and 135 kg. The speed of the electric vehicle that is varied is 10 km / h, 20 km / h, and 30 km / h, as well as the current flowing. The trial was carried out with an electric vehicle according to the planning with a predetermined trajectory. The data obtained will be compared with the kinetic energy generated from the movement of the electric motorcycle following the following equation:

$$\eta = \frac{\text{Energi Kinetik}}{\text{Energi Listrik}}$$

$$\eta = \frac{m.v}{P.t}\ x\ 100\ \%$$

RESULTS AND DISCUSSION

The mechanical data owned is entered into the formulation of equations 2 to 5 to obtain the traction force value in equation 1.

Aerodynamic Style:

$$F_{\text{ad}} = \frac{1}{2}\rho A_f\ C_d\ v^2$$

$$F_{\text{ad}} = \frac{1}{2}(1{,}25)(1{,}5\ x\ 0{,}6)\ (0{,}5)(11{,}11)^2$$

$$F_{\text{ad}} = 34{,}71\ N$$

Rolling resistance style:

$$F_{\text{rr}} = \mu_{\text{rr}}\ x\ m\ x\ g$$

$$F_{\text{rr}} = (0{,}004)\ (176)(9.81)$$

$$F_{\text{rr}} = 69\ N$$

Hill climb style assuming flat road:

F_{hc}= W sin θ

F_{hc}= (66.2) (9.81) (0 °)

F_{hc}= 0

Acceleration Force:

Fla = x a

Fla = (176)(1.11)

Fla = 195.36 N

So the value of the traction force is:

$Fte = Fad + Frr + Fhc + Fla$

Fte = 34.71 + 6.9 + 0 + 195.36

Fte = 236.97 N

With this traction force, the BLDC motor power required is as follows:

$P = Fte \times v$

= 236.97 × 11.11

= 2,632.73 W

Based on the calculation results above, the capacity of the motor used can be determined. The drive motor used has a power capacity of 2500W which has a maximum voltage of 63 VDC. The peak current that will be held by the controller is very important, which functions for the survival of the controller where the current passing through the controller can be held and does not cause damage to the components. So to minimize the failure, namely determining the peak current that can be held by the controller, namely:

$$I = \frac{P}{V} = \frac{2500}{63} = 39{,}68\ A$$

Next is the performance testing of the Electric motorbike on straight and flat tracks with various loads and speeds can be seen in the table below:

Table 1. Testing at a Maximum Speed of 10 km/h

Rider Weight (Kg)	Voltage (V)	Current (A)	Input Power (W)	Time (s)
58	52.85	9.05	478.2	1.8
95	52.25	10.02	523.5	1.9
135	52.09	16.72	870.9	2

Table 2. Testing at a Maximum Speed of 20 km/h

Rider Weight (Kg)	Voltage (V)	Current (A)	Input Power (W)	Time (s)
58	51.25	12.08	619.1	2.1
95	51.19	14.23	728.4	2.4
135	50.02	18.63	931.8	2.9

Table 3. Testing at a Maximum Speed of 30 km/h

Rider Weight (Kg)	Voltage (V)	Current (A)	Input Power (W)	Time (s)
58	50.76	14.88	755.3	2.7
95	49.92	15.56	776.7	2.9
135	48.36	21.83	1,055.6	3.7

The table above shows the motorcycle test with various loads and maximum speeds during the initial acceleration of the electric motorcycle. At this initial acceleration, the BLDC motor will require the largest starting current for the initial drive of the electric motorcycle. The current value read is used to measure how strong the BLDC motor moves the motorcycle along with the load. The closer the measured current value at the start of the electric motorcycle movement to its nominal current value, the harder the motor is working to start the movement. The lowest current consumption value is 9.05 A which occurs in testing with a load of 58 kg and a maximum speed of 10 km/h.

Meanwhile, the largest current value is 21.83 A which occurs in testing with a load of 135 kg and a maximum speed of 30 km / h. The highest current value is still far below the nominal current value of the BLDC motor, which is 39.68 A. The difference in current value reaches 17.85 A from the nominal current of the BLDC motor. This indicates that the 2500 Watt BLDC motor does not experience problems in moving the electric motor. At the same maximum speed, the heavier the load given, the greater the current consumed by the motor. Likewise, with the same load value, increasing motor speed also results in an increase in the current consumption of the electric motor

By using equation 7 above, each test can calculate the efficiency value of the use of electrical energy against the kinetic energy produced. The mass calculated is the mass of the motor plus the mass of the rider. The table below is the result of the efficiency calculation for all tests

Table 4. Efficient Use of Electrical Energy into Kinetic Energy

Maximum speed (km/h)	Total Mass (kg)	Efficiency (%)
10	58	67.38%
10	95	95.43%
10	135	77.50%
20	58	89.22%
20	95	86.85%
20	135	99%
30	58	85.32%
30	95	26.53%
30	135	07.05%

The values in the table above can be calculated using the following equation:

$$\eta = \frac{m.v}{P.t} \, x \; 100\,\%$$

$$\eta = \frac{58 \; x \; 10}{478,2 \; x \; 1.8} \, x \; 100\%$$

$$= 67{,}38\%$$

CONCLUSION

Testing on electric motorcycles with variations in load and initial speed shows that the current required to drive the electric motorcycle in the acceleration phase is only 38.56% of the nominal current value, so it can be concluded that the selection of a 2500 Watt BLDC motor. The largest current value is 21.83 A which occurs in testing with a load of 135 kg and a maximum speed of 30 km / h. The lowest current consumption value is 9.05 A which occurs in testing with a load of 58 kg and a maximum speed of 10 km / h while the lowest current consumption value at a load of 95 kg and a maximum speed of 20 km / h reaches 12.08 A.

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