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Design of Efficient In-Wheel Motor for Electric Vehicles

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Abstract

This research paper deals with the design and development of an in-wheel motor for electric vehicles. The proposed motor generates a 350-watt power drive with a power source of two 12V batteries. The batteries are connected in series to increase the voltage to 24 volts and 18.23 A. The in-wheel motor is based on the principle of a DC electric motor to drive the vehicle wheels so that the mechanical components of the transmission and the energy loss are minimized. The proposed in-wheel motor has 46 poles, 51 slots and 51 teeth. In addition, the method lowers the maintenance cost. This research work assumes the maximum weight of 70 kg and the running speed of 20 km/hr. The experiment results show that the output power and efficiency of the in-wheel motor are subject to the variation in input power given that the input voltage remains constant at 25.41 volts. The maximum efficiency of the in-wheel motor of 82.56% is achieved at 2.5 N-m torque. The maximum torque of 6.25 N-m is achieved with the input power of 348.76 watts.

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Keywords: In-Wheel Motor, Electric Vehicle, Power drive;

1. INTRODUCTION

Most current technological developments in electric vehicles have centered on improving energy efficiency. Several existing research studies thus focus on the development of vehicle propulsion and power transmission. The aim of this research study is to design and develop an in-wheel motor that reduces the power loss and power transmission in the vehicles. In particular, [1], [2] and [3] researched and developed the in-wheel motor technology

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for electric vehicles. The in-wheel motor technology requires the mounting of an electric motor directly on the wheel hub without gears or chains to minimize the number of mechanical power transmission parts and thereby reduce the energy loss [4]. The in-wheel motor operates by converting the electric power from a car battery into mechanical energy to directly drive the wheels rather than through the power transmission parts. This therefore allows for more efficient use of energy.

This research study focuses on the design and development of a small-scale in-wheel motor for electric vehicles. The design is based on the principle of a Blush Less DC Motor (BLDC). The experiments to study the performance of the in-wheel motor were carried out under a load condition of 70 kg in a laboratory setting.

Nomenclature

Pm	drive power (watts)
F	total force to drive a vehicle (N)
v	vehicle velocity (m/s)
Pe	power supply (watts)
η	motor efficiency
m	number of winding turns per phase
P	number of poles
I	current (A)
L	conductor length (m)
R	radius of wheel (m)
B	density of magnetic field (T)

2. EXPERIMENT

The assumptions made in this research work are as that the vehicle can be driven at a speed of 20 km/h on a horizontal plane and has a load of 70 kg.

2.1. Equipment

The devices to carry out the experiments include a Mosfet, an Amp meter, a volte meter, a Techo-meter, a torque adjusted unit, a DC Power Supply, a torque meter and the in-wheel motor, all of which are presented in Figure 1. The performance of the in-wheel motor is determined by varying power load.

2.2. Theoretical Framework

The equation to determine the drive power of the proposed in-wheel motor is as follows:

$$Pm = F \times v \tag{1}$$

where *Pm* is the drive power (watts)
F is the total force to drive a vehicle (N)
v is the vehicle velocity (m/s)

The power supply can be determined from:

$$Pe = Pm / n \tag{2}$$

where

Pe is the power supply (watts)

η is the motor efficiency

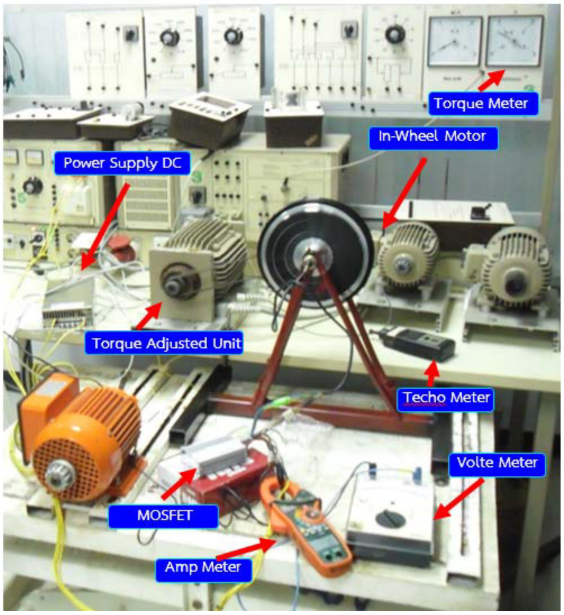


Fig. 1. The photo image of the in-wheel motor test station.

The number of winding turns per phase (m) is calculated from:

$$m = P/phase \pm 1 \quad (3)$$

where

P is the number of poles

phase = 3 phases

The number of winding turns can be expressed as:

$$N = T/(2 \times m \times I \times L \times R \times B) \quad (4)$$

where

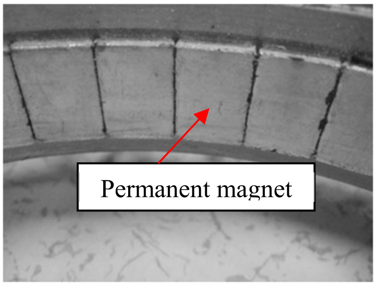
I is the current (A)

L is the conductor length (m)

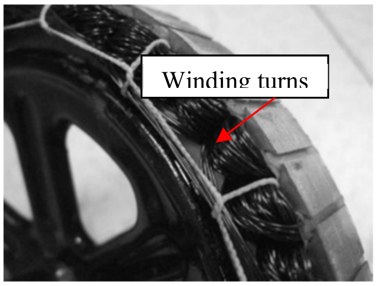
R is the radius of wheel (m)

B is the density of magnetic field (T)

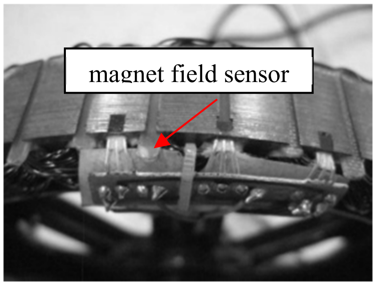
Since the in-wheel motor is intended for a small vehicle driven on a level road with a speed of 20 km/h and a 70kg load, the motor is designed to operate with a 24V, 18A DC power source. The power to drive the wheels is 350 watts. Forty permanent magnets of 3 mm thick and 20 mm high; and 46 poles are used in the proposed in-wheel motor. The stator is 200 mm in diameter and 20 mm thick. The Distributed LRK technique is adopted to produce 3-phase coils. The winding pattern is of AabBCcaABbcC. The motor has 51 slots and each slot is made up of 17 turns of wiring. Figure 2 shows the construction of the in-wheel motor.



(a)



(b)



(c)

Fig. 2. The construction of the in-wheel motor: (a) the permanent magnet (b) winding turns and (c) the location of the magnet field sensor.

2.3. Experiments

The experiments were carried out in a laboratory by connecting the in-wheel motor to the test station. Load is applied by the torque adjusted unit. The in-wheel motor revolutions, current, input power, output power and torque are observed and documented. Figure 3 depicts the schematic of the devices connected to the test station.

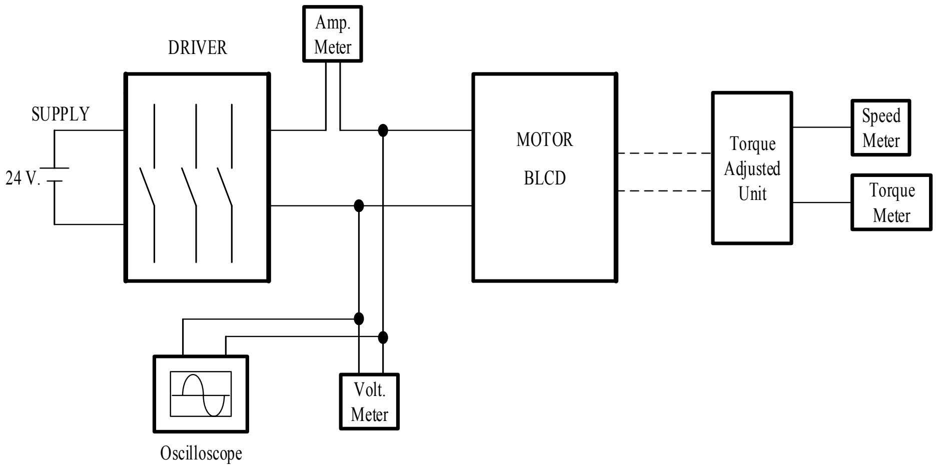


Fig. 3 The schematic of the connected devices.

3. RESULTS AND DISCUSSION

The input voltage signal is utilized to control the in-wheel motor at different speeds. In Figure 4, the measured average power supply and frequency of the input voltage are 21.1 volts (originally 24 volts) and 131.1 Hz, respectively. The loss of power supply is attributed to the signal input ripple. The speed of the proposed motor at 21.1 volts and 131.1 Hz is 533 rpm.

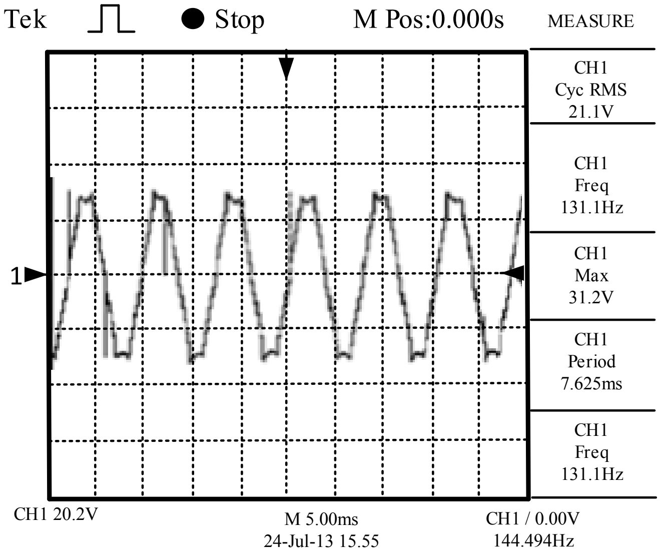


Fig. 4. Input signal voltage with 131.1 Hz

In Figure 5, the speed of the in-wheel motor is reduced to 453 rpm, which is achieved by a reduction in the current (I). The reduction results in a drastic increase in the measured frequency of the input voltage to 582.7 Hz given a 24-volt power supply. In addition, the reduction in *I* yields the minimum and maximum voltages of 17.5 and 30.4 volts, respectively. However, the ripple voltage fluctuations have no effect on the revolution speed.

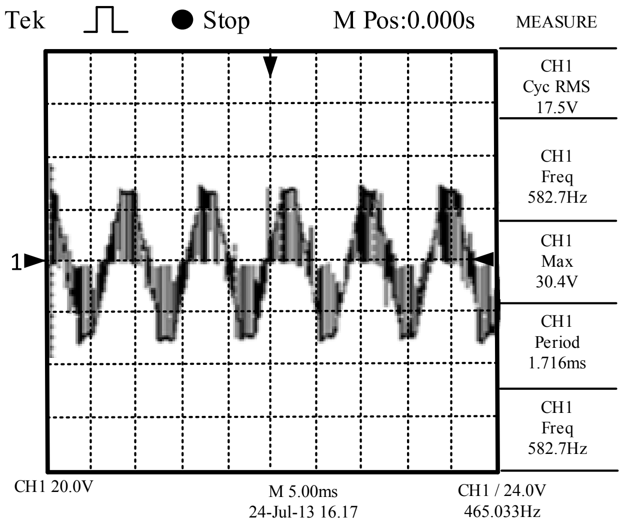


Fig. 5. Input signal voltage with 582.7 Hz

Variation of input current is required to control the in-wheel motor speed, keeping the input voltage constant. The signal voltage frequency varies with increase in current.

Table 1 summarizes the experiment results of the in-wheel motor. The results show that the speed of the in-wheel motor (in rpm) decreases with increase in the input current (i.e. from 533 rpm at 0.68A to 395 rpm at 13.7A), keeping the input voltage relatively constant at 25.41 volts. The input power increases with increase in torque. At the low end of input power (17.28W), the revolution of the in-wheel motor is approximately 533 rpm with an input voltage and an input current of 25.41 volts and 0.68A, respectively. The performance (Eff.) at this level is 35.36% and increases with increase in the input current and input power and decreases after the input current and input power reach 5.81A and 147.6W, respectively.

Table 1. The laboratory data and experimental results.

Step	Volt. V	Cur. A	Input Power W	Tor. N-m	Rev. rpm	Output Power W	Eff. %
1	25.41	0.68	17.28	0.11	533	6.11	35.36
2	25.41	1.36	34.56	0.33	522	17.94	51.91
3	25.42	1.83	46.52	0.55	517	29.62	63.67
4	25.42	2.47	62.79	0.85	509	45.07	71.78
5	25.42	3.23	82.11	1.21	500	63.02	76.75
6	25.41	4.03	102.4	1.61	489	82.01	80.09
7	25.41	4.86	123.4	2.03	479	101.29	82.02
8	25.41	5.81	147.6	2.5	468	121.88	82.56
9	25.41	6.88	174.8	3.02	455	143.14	81.88
10	25.41	7.91	200.9	3.53	443	162.89	81.04
11	25.41	9.01	228.9	4.06	433	183.12	79.99
12	25.41	10.2	259.9	4.84	402	202.68	77.97
13	25.41	11.3	287.9	5.2	409	221.54	76.95
14	25.41	12.1	309.7	5.68	398	235.48	76.02
15	25.42	13.7	348.7	6.25	395	257.16	73.74

Figure 6 shows the input power, output power, and efficiency of the in-wheel motor under various load conditions. The maximum efficiency is 82.56% with the maximum input power and output power of 147.63 and 121.88 watts, respectively. At this level, the in-wheel motor revolves 468 rpm with a maximum torque of 2.5 N.m.

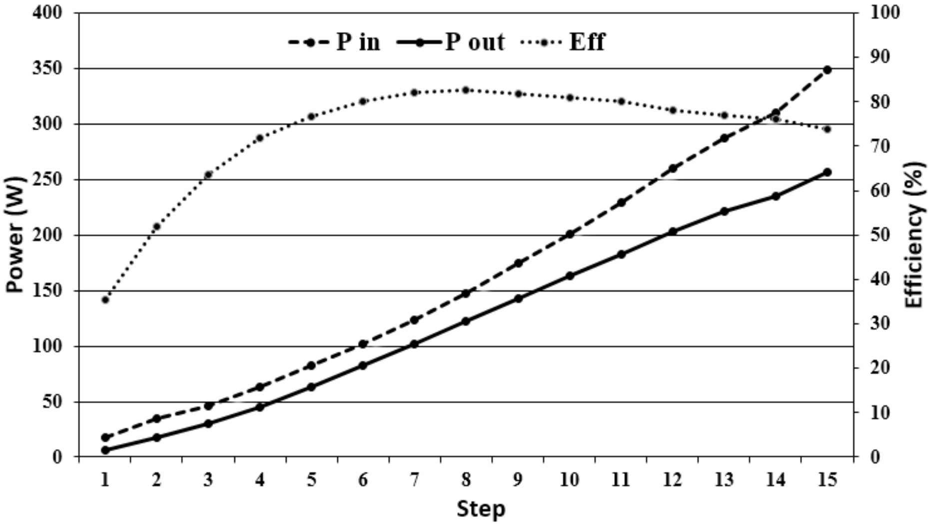


Fig. 6. The experimental results of the in-wheel motor under various load conditions.

4. CONCLUSIONS

The experiment indicates that the proposed in-wheel motor is able to drive a 70-kg-load vehicle traveling at a speed of 20 km/h. The in-wheel motor is tested in the laboratory by varying power load. The maximum efficiency of 82.56% with the speed of 468 rpm is achieved at 2.5 N.m torque, with a 5.81A input current. The maximum torque achieved is 6.25 N.m with the input power of 348.76 watts and 13.72A, but the speed of the motor is reduced to 395 rpm.

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