OPTIMAL DESIGN OF ELECTRIC BICYCLE

(ELECTRIC BICYCLE MOTOR)

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JUDUL: **OPTIMAL DESIGN OF ELECTRIC BICYCLE (ELECTRIC BICYCLE MOTOR)**

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Electric bicycle is a vehicle empowered by electric motor in order to move. It is also known as e-bike. For the power source of the electric motor, certain country used different power, because it is depends on the Law of the country. Basically, rechargeable batteries that used for the e-bike is 15 to 20mph which is can travel 24 to 32km/h. The invention of the electric bike is as a proof that the engineering field keep advancing, the invention of the electric bicycle make it replacing the old bicycle in the market.

Although the electric bicycles are using electric motor, it still called as bicycle rather than motorcycle. This is because it identity as bicycle is still fixed which is most of it part are belong to bicycle. So, it not included in transportation law which require the certification and operation as on good motor vehicle. It is not need to have license to ride the electric bicycle.

The electric bicycle is not a fully motorized vehicle, it's just semi motorized bicycle, which is still have pedal, gearing, brake, and frame design and so on. This electric bike use NiMH which is a common power supply used on the electric bicycle. This kind of the battery is rechargeable and a lighter and denser capacity batteries which is make it the designing of an electric bicycle more handful and easier. The electric bicycle is not like a motorcycle in many concept, either it design or it power supply. Besides that, the electric motor is also used lower power compared to motorcycle which is the bicycle still need the rider to pedal the bicycle. There is some type of electric bicycle that commonly used by all the people in term of weight and frame material type.

Weight of the bicycle also plays an important role in the speed of the bicycle. The weight of the bicycle depends on the purpose of the bicycle been used, it is

either for competition so there is few of common weight that been used for the bicycle. On the older bicycle, the weight of the bicycle is about 35 or 40 pounds, this kind of weight was back older day before the technology of the bicycle still not growing. Now, the weight of the bicycle was improved, the weights of the bicycle have been reduced about to 15 and 25 pounds. The improvement of the weight of the bicycle is for the purpose of bicycle handling and speed of the bicycle.

Next is frame of the bicycle, there is few of material that is popular to develop the bicycle frame, it purpose is to make the bicycle lighter and strong frame. The type of materials that commonly used to develop bicycle frame are Carbon fiber, Steel, and Titanium.

Most popular material used in develop bicycle frame is carbon fiber, the term of carbon fiber describe this material have various different composites that include different polymers, carbon and graphite that are link by an epoxy-resin matrix which is sometimes containing metals or ceramics. This carbon fiber is one the advanced composites which offer great possibilities for light weight and high-performances in many way, this is because layer of composite can be insert only where it needed to be placed. Fiber also called whiskers of material used to stabilize dynamic forces due to different degrees and direction on different part of the bicycle frame.

Next is steel, which also commonly used to develop the bicycle frame. Steel is the material which used for many bicycle frames. Lots of bicycle designers have used their many years experience in refining the design of steel bicycle. Steels offers a comfortable ride and frame made up from steel can act as a spring to store energy when the rider causes the frame to flex at different parts of the pedals stroke. The stored energy by the steel can be released and converted to forward motion another part of the pedal stoke. Steel frame can be repaired with low cost and when there is damaged, steel bicycle can show or reveal frame stress injuries before the frame break. Steel bicycle frame break slowly compared to aluminum frame which break suddenly when there is failure on the frame. Most of the high quality bicycle frames are made of steel tubing which has been alloyed with chromium and molybdenum, sometimes also alloyed with manganese and molybdenum.

Beside than Carbon fiber and Steel frame, Titanium also one of the popular material used to develop bicycle frame. The characteristic of the Titanium as bicycle frame is almost similar to steel but it have more advantages than both carbon fiber and steel. Titanium is lighter than the carbon fiber and steel, also the strength to overcome the stress by force or impact is higher than steel and fatigue life of the titanium is more than steel. Even though titanium wins all aspect for develop the bicycle frame, but the cost to develop frame from titanium is higher than steel and carbon fiber.

1.2 Problem Statements

This project is proposed in order to design the electric bicycle that use for the travelling and can be used in long distance. The designing of the electric bicycle is included of the frame design, motor control and gearing system design and the riding comfort for the rider. The design is done in group but with separate task and objective, which is each of people done different part for the electric bicycle. In this proposal, the motor control and gearing system design will be proposed.

The motor that would be used for the gearing system need to be done research and analysis so that the suitable motor for the electric bicycle can be choose. Research and analysis for the motor is needed because it one of the main component of the electric bicycle in order to move. The limit of the motor that would be used in the project also must be noted, because it will tell how much the load or speed the motor can withstand when heavy duty task are applied on the bicycle. The torque of the shaft also must be calculated which is will be used as the reference of the motor speed on the gearing system.

The type of motor that will be used for the electric bicycle is one of the important thing or element that can influence the speed, duration of the electric bicycle can move with the assistant of electric bicycle that was chosen. Besides that, the type of motor that were be used also important in selection of power supply. This is because; each motor has its own specific power or voltage that the motor used. Even the same type of motor, it power usage still has differences because of it differences in specification. All the motor that will be compared and analyze is DC motor which is

suitable for electric bicycle design, because the power source of the motor is will be battery.

By the way, the position of the motor also must be done a research and analysis; it cannot put the motor on the electric bicycle without do analysis the effect of the motor position to the electric bicycle speed and rider comfort. The position is consider either embedded at the rear tire, front tire, near the pedal and on the tire with shaft drive the tire by direct contact.

1.3 Objective

The aim for this project of making the electric bicycle which is included the designing of the frame, comfort, the way of powered and controlled it. Hence, my objective for this project is:

i. To choose a motorize system for the electric bicycle which is can use minimum of power supply during travelling.
ii. To select the type of motor for electric bicycle that can compatible with the bicycle.
iii. To state position of the motor, so that the rider comfort can be optimize.

1.4 Scope of Study

In my part/ project task, there is three scope of being studied. They are:

i. Choosing motorized system that involves with mechanical part and electrical field, which is known as power drive system. It is studies of how we use or applied the electric motor in the gearing system.
ii. Selecting the type of motor that suitable for the electric bicycle.
iii. Decide the suitable position of the motor, it is to make sure the comfort for the rider is optimize.

1.5 Conclusion

This chapter discuss about the background of the electric bicycle which included the problem statement for this project that related to motor that suitable for the electric bicycle. Included in this chapter is objective and scope of study for this project which used as a guide for completing the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Electric bicycle is a vehicle that known or called as e-bike, it is a bicycle which is assist by the electric motor to set this vehicle in motion. The bicycle use electric dc motor which is receiving power supply from rechargeable batteries. Within batteries powered the motor, the bicycle can travel up to 15 and 20 mph, but this range depends on the batteries and the motor power limit which is each of the components has their own specifications and limitation. The electric bicycle is not restricted or bend to the motorist vehicle law even though it is power by motor, it still considered as bicycle which is the identity of the bicycle is still fixed on it. [1]

The electric bicycle is a free from pollution, this is because it using electric source, rather than gasoline, it will cause pollution to environment, and it will be more similar to a motorcycle. Hence, the using of dc motor that power by batteries is used on the electric bicycle. The electric bicycle is still used pedal to for pedaling, it just adding the motor, batteries, electronic components and throttle for speed. This add up is for assist the rider in certain condition which is when pedaling away up the high slope, more power are needed, so the motor can assist the rider by provide pedaling power to the rider during pedaling up the high slope. [2]

The electric bicycle can be separate in few parts in context of its components and design consideration in order to produce a good electric bicycle, first is the motor and motor control part which related to the electric bicycle motion that assist by the motor, it all about type of the motor that efficient and most suitable for this kind of bicycle. Second is electric and electronic part where this part is about the circuit of the motor control system, like the connection of the battery, motor interface by the gear and regenerative brake of the motor. Then, other part is frame design part and the rider comfort consideration of design which related to rider comfort during riding the bicycle; it is including the type, height, design and weight

of frame that used to build the electric bicycle. By the way, type of material and position of the seat also play important role for the rider comfort, this because seat of the bicycle can effect rider heath and body, if the seat were design with consideration of rider health by design the seat with safety material that can reduce impact during pass through the bump, then it can at least guaranty rider health when riding the bicycle, But, in this report, the motor components are only focused. This is because this project focuses on this part of the electric bicycle. Hence, the consideration that will be included for the motor are, torque calculation, type of motor, motor power and etc. [2]

2.2 Motor

2.2.1 Type of motor used

The motor that was chosen for the electric bicycle is the Brushless DC (BLDC) motor. BLDC motor is also known as electronically commutated motor (ECM). The BLDC motors are powered by DC electric source in order to function. The source is supplied via integrated inverter or more known as switching power supply. The integrated inverter is functioning by produce AC electric signal to drive the motor [2].

The BLDC motor was chosen because this type of motor has many advantages compared to other motor. The most obvious advantage of BLDC motor is, it has less brushes and physical commutator. From this, it make less of the part that will wear out or break and need to be placed compared to brushed motor. Also, BLDC motor is more reliable; last longer and more efficient than other motor. BLDC motor can operate with less noise and electromagnetic interference compared to brushed motor. By the way, excellent efficiency and reliability that offers by BLDC motor follows with its low weight and can be obtain in many size, make this kind of motor most suitable choice for many application, especially for the electric bicycle.

The motor part for the BLDC motor is commonly a permanent magnet synchronous motor, also can be a switched reluctance motor or induction motor. Even though Brushless DC motor is described as stepper motor, this nickname not suitable for BLDC motor that designed specifically to be operated in a mode where

they commonly stopped with the rotor in a defined angular system or specific angle. [2]

The basic construction of Brushless DC motor are likely similar to the AC motor which is known as the permanent magnet synchronous motor. In Figure 1 is showing the structure of the 3-phase brushless DC motor. The winding of the stator of BLDC motor is similar to AC motor that have polyphase, the number of permanent magnet consist of one or more than one poles. The differences of BLDC motors from the AC synchronous motor are in the way it does detect the position of rotors in order to produce signaling to control the electronic switches which is shown in Figure 2. Also, the common position or pole sensor is called Hall element,. [3]

When the BLDC motor is compared to others motor, there is several advantages that are shown by the BLDC motor, these advantages are:

i. Better speed versus torque characteristic
ii. High dynamic response.
iii. High efficiency
iv. Long operating life
v. Noiseless operation
vi. High speed ranges

Also, the ratio of torque that delivered to the size of motor is possibly higher which is making the BLDC motors application is useful when the space and weight are mention. [4]

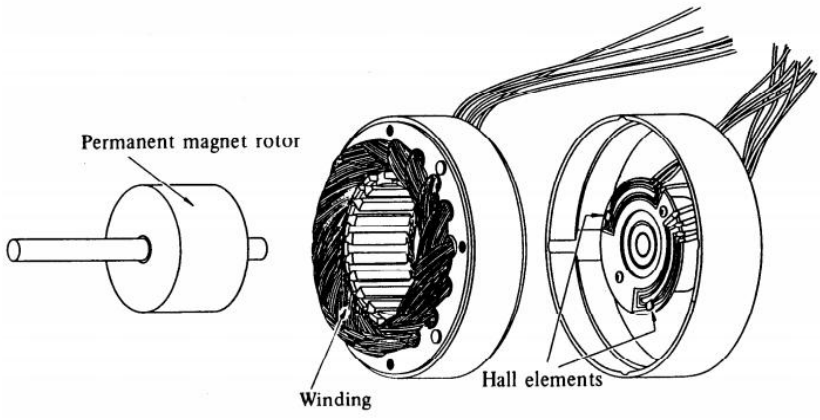

Figure 2.1: BLDC motor part layout. [3]

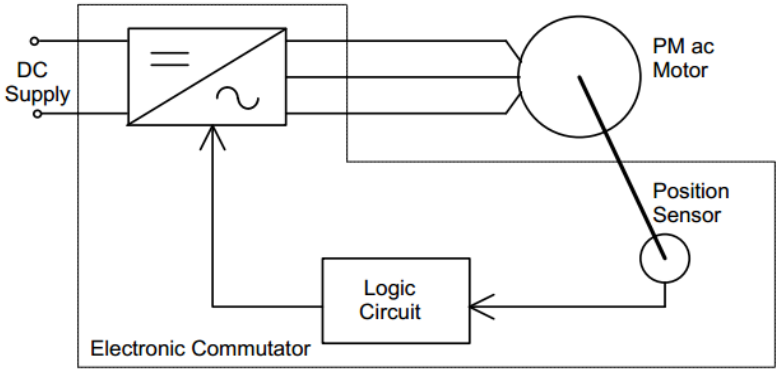

Figure 2.2: Brushless DC motor: Permanent magnet ac motor + Electronic commutator [3]

2.2.2 Hall Elements

Hall elements in the BLDC motor is a flux conversion which can convert the magnetic flux density directly into the voltage which is known as Hall voltage, it is functioning as a magnetic sensor. The application of a magnetic field in a direction to the current I_C flow direction in the Hall elements cases the force to act on the electron in a direction to both the current I_C and magnetic field. Then, the potential difference which is called the Hall voltage to occurs on both of the hall elements end. [5]

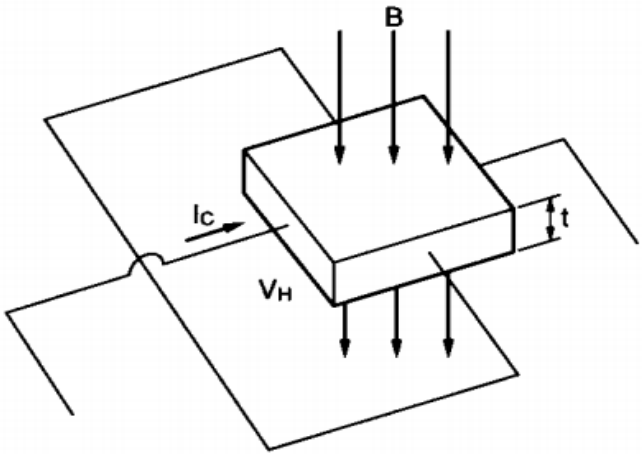

Figure 2.3: Hall Element [5]

By the way, the Hall elements is also known as hall sensors which is define that it is necessary to known the position by the controller, hence, the hall sensors

likely tell the controller about the angular information of the rotor to the controller. This is because the voltage cannot be applied in order to create torque. All angular position of the rotors is providing by this sensors [6].

When the magnetic field is applied to a system of the rotors with an electric current, a hall voltage is perpendicular to the field and generates the current. The hall sensors act by sending three signal that consist of six states. Each state is corresponding to certain position that shows by the rotors, the state can be determined by using 60˚ accuracy [6]. This accuracy is illustrated in figure 4.

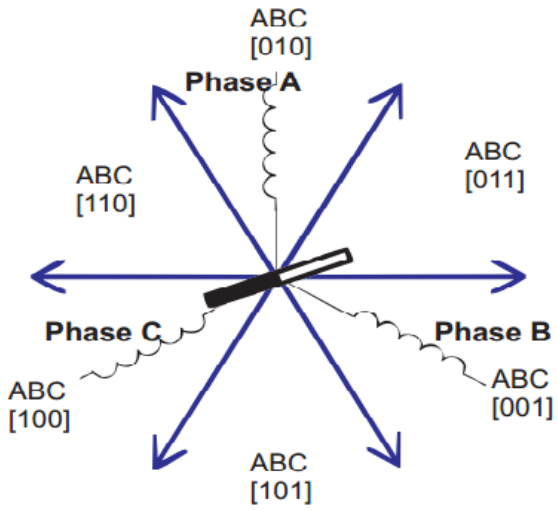

Figure 2.4: six hall sensors stated of the rotors [6]

Even though, some said that brushless dc motors are similar with the conventional dc motors in theirs static characteristic, actually both of motor have obvious differences in several aspect. If both motors were compared in terms of nowadays technology, it more clearly information when the differences is used rather than using similarities, this because, it is helpful in understanding application each of the motors in certain ways. If the function of electrical motor was put in discussion, it is must not ignore the significance of windings and commutation of both motors. Firstly, commutation is refers to the process which convert the input of direct current to alternating current, then properly distribute the current to each of the winding in the armature. The conventional dc motor commutation, it is undertaken

by brushes and commutator, while in BLDC motor, it is done by using semiconductor such as transistor. In Table 1 below is comparison of convectional and BLDC motor. [3]

	Conventional motor	Brushless motor
Mechanical structure	Field magnet on the stator	Field magnets on the stator Similar to AC synchronous motor
Distinctive features	Quick response and excellence controllability	Long-lasting Easy maintenance (usually no maintenance required)
Winding connection	Ring connection The simplest: Δ connection	The highest grade: Δ or Y-connected three phase connection Normal: Y-connected three-phase winding with grounded neutral point, or four-phase connection. The simplest: two-phase connection
Commutation method	Mechanical contact between brushes and commutator	Electronic switching using transistors
Detecting method of rotor's position	Automatically detected by brushes	Hall elements, optical encoder, etc.
Reversing method	By a reverse of terminal voltage	Rearranging logic sequencer

Table 2.1: Comparison between conventional and BLDC motors. [3]

In addition, the stator creates the magnetic field which is the rotor rotate at the constant frequency. This BLDC motor did not experience the "slip" that is

commonly occurs in induction motors. Corresponding to its type the stator have the equivalence number of winding, the BLDC motor can came in single-phase, 2-phase and 3-phase. Amongst this kind of motors, 3-phase motors are widely used. [6]

2.2.3 Stator

The stator of a BLDC motor consists of stacked steel laminations with windings located in the slot that are axially cut along the inner periphery just like in figure 5 shows. The BLDC motor stator maybe resembles to induction motor, but it is for the certain way, but not in all aspect. The BLDC motors have star connection of three stator winding which is each of the windings are consist of numerous coils interconnected to form a winding. The windings then were dividing over the stator in order to form even number of poles. [4]

For the stator windings, there are two types of stator which is trapezoidal and sinusoidal motors. The differentiation of the basis interconnected coil in the stator windings gives different types of back Electromotive Force (EMF). [4]

Back EMF is voltages that generated by rotation of the BLDC motors. The back EMF is opposing the main voltage which is supplied to the windings based on the Lenz's Law. The back EMF is in opposite direction of the energized voltage in context of polarity. There are few factors that mainly influences back EMF:

- Rotors angular velocity
- Rotor magnets magnetic field that generated
- Number of turns in the stator windings.

Equation of the Back EMF is:

$$\textbf{Back EMF} = (E) \propto N l r B \omega$$

Where:

N- The number of windings turns per phase,

l – The length of rotor,

r- The internal radius of the rotor,

B- The rotors magnetic field density

ω- Motor's angular velocity.

After the motors are designed, the magnetic field of the rotor and the number of turns in the stator winding remain unchanged. The potential difference that crosses the windings can be calculated by subtracting the back EMF value from the voltage supply. [4]

When the signal is triggered, the trapezoidal motor gives a back EMF in trapezoidal form and the sinusoidal motor's back EMF produce sinusoidal pattern. This pattern can be seen in Figure 5 and figure 6. By the way, the phase current for the back EMF also have trapezoidal and sinusoidal variations in the respective types of motors, which from this condition, it cause the torque output produce by sinusoidal motor was smoother than that of trapezoidal motor. Even so, there is increasing of the copper intake by the stator windings because of sinusoidal motors take the extra windings interconnection that cause by the stator peripheral.

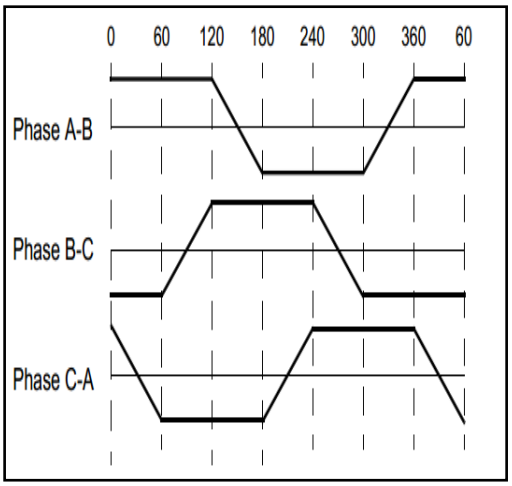

Figure 2.5: Trapezoidal Back EMF [4]

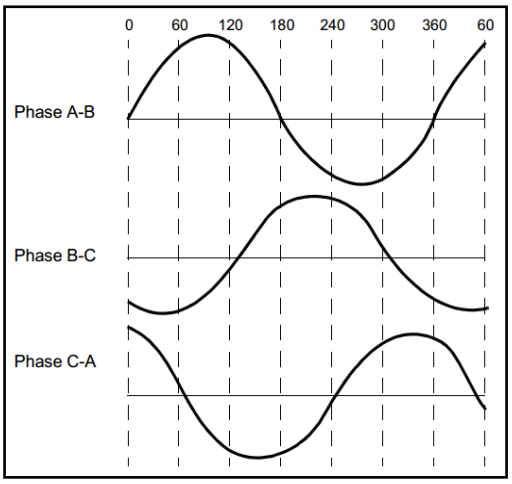

Figure 2.6: Sinusoidal Back EMF [4]

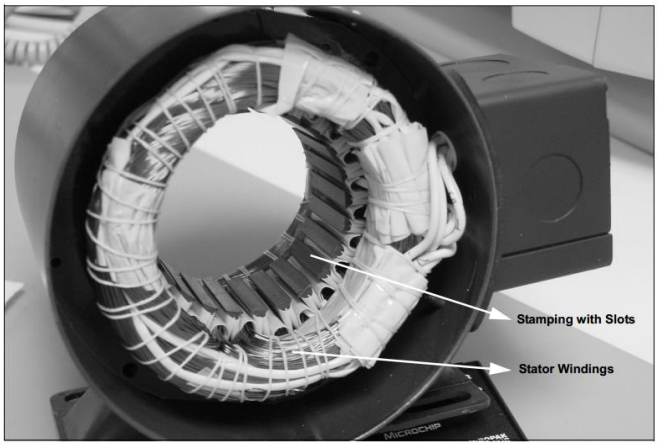

Figure 2.7: Stator of BLDC motor [4]

2.2.4 Rotor

Rotor is a non-stationary part that rotates in an electric motor, electric generator or alternator. The rotor rotation is because by the wires and magnetic field of the motor that is arranged so that a torque is developed at around the rotor's axis. [4]

The rotor is consist of permanent magnet and can be divide from two to eight pole pairs with alternate pattern of North (N) and South (S) poles. If refer to the requirement of field density for the rotor, proper magnetic field are chosen to make the rotor. In figure 8 is show the cross section of the rotor. [4]

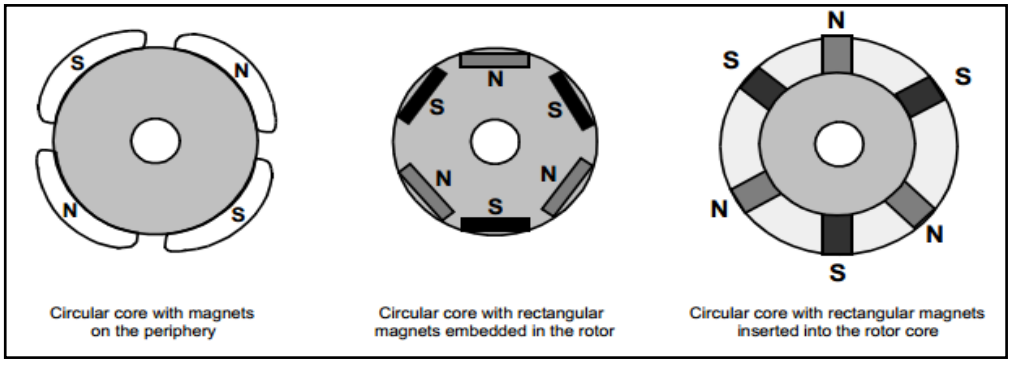

Figure 2.8: Rotor Magnet Cross section [4]

In BLDC motor, iron losses phenomena not only occur in the stator but also in rotor. The rotor may experience iron losses that consist of three elements, the elements are the eddy current losses, the hysteresis losses and excess losses. To

detect the Iron loss, the information and knowledge about the Flux density are necessary. The Iron loss cannot be detected blindly and with lack of information about the flux. This is important for motor configuration, especially the motor with fractional number of teeth per poles and phase [7] [8].

2.2.5 Hall Sensors

The commutation of the BLDC motor is not the same with brushed DC motor which is the BLDC motor is controlled electronically. When the rotation of the rotor is about to start, the windings will be energized in a sequence. Before understanding about the winding that will be energized by sequenced, the rotor position of the motor must be know first. As said before, the position of the rotor is sensed by the three Hall Effect sensors which are embedded into the stator. [4]

The hall sensor gives either high or low signal when the rotor magnetic poles pass the sensor. The signals that are produce are purpose to indicate the poles near the rotor. The exact sequence of commutation of rotor is determined by this way.

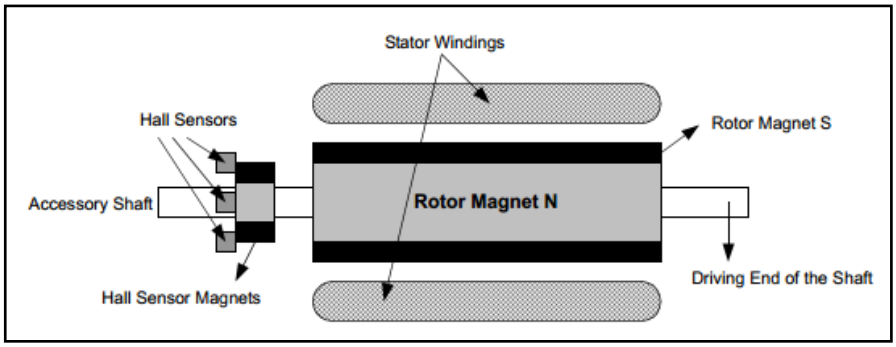

Figure 2.9: Transverse Section of BLDC motor [4]

2.2.6 Torque/Speed Characteristic

The BLDC motor have special torque-speed characteristic that is make it more optimal choice of the motor to be used on Electric Bicycle. The BLDC motor have the speed-torque characteristic that is can be controlled to be similar with permanent magnet DC motor. This kind of advantage is needed for designing electric bicycle so that it has optimal speed during moving. It is also needed to analyze the

consumption of torque and speed during going up the slope, go down the slope and pedaling on flat surface or road. This torque-speed characteristic of BLDC motor is one of the elements that are needed to be pay attention if performance of BLDC motors is mention [9] [10].

Before the torque or speed or any other value that produce by BLDC motor been determined, the analysis of motor commutation periods are necessary to be done, this purpose is to have a accurate result of the torque-speed characteristic [11]. This topic will be discussed in methodology of this project.

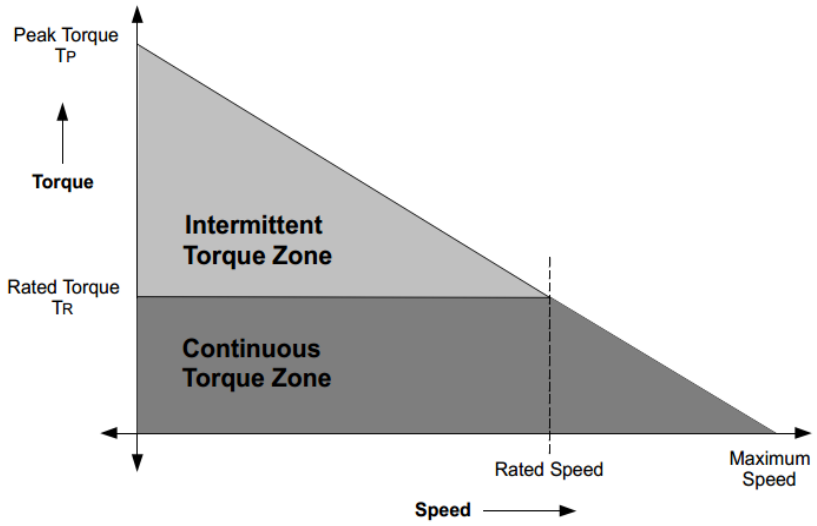

Figure 2.10: Torque-speed characteristic [4]

2.3 Conclusion

This chapter is about the literature review of the electric bicycle and electric bicycle which is BLDC motor. This chapter explains about the characteristic of the motor that should be used for the electric bicycle. Also, component of the motor also explained in this chapter. From this chapter, it is important that to know the characteristic of the motor should be used in order to achieve optimum design of electric bicycle.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In choosing an motor for electric bicycle, which is Brushless DC motor (BLDC), there is few method will be used, the method is torque calculation, Losses, efficiency,

3.2 Torque Calculation

Before using any motor for Electric Bicycle, torque calculation is necessary to be considering, this is because each motor have its own torque limit for the motor to hold certain load. If a motor were used without calculating its torque or how much torque can the motor provide amount of torque to the electric bicycle. If the motor have low or insufficient amount of torque, this can lead to Electric Bicycle not even move or maybe can move but only without any load or rider. This is why Torque Calculation is important when choosing suitable motor for Electric Bicycle [4]. For this section, only formula will be stated.

3.2.1 Peak Torque (T_p) Requirement

The peak torque or also called maximum torque is required for the application, it can be calculated by summing the load torque (T_L), torque due to inertia (T_J) and the torque need to overcome the friction (T_F) [4].

$$\Diamond\ T_P = (\ T_L + T_J + T_F)*1.2 \quad \text{[N/m]} \qquad \textbf{(3.1)}$$

The torque due to inertia(T_J) is the torque that required accelerating the load from rest or from lower speed to higher speed. This can be calculated by using the product of load inertia, with the rotor inertia and load acceleration [4].

$\Diamond T_J = J_L$ + M * α [N/m] **(3.2)**

Where:

J_L + M is the sum of the load and rotor inertia

α Is the required acceleration

3.2.2 RMS torque Requirement (T_{RMS})

The (T_{RMS}) or Root Mean Square (RMS) torque can be roughly translated to the average continuous torque required for the application. This value depends on several factors. The peak torque(T_P), load torque(T_L), torque due to inertia (T_J), frictional torque (T_F) and acceleration, deceleration and run times [4].

$$\therefore T_{RMS} = \sqrt{[\{T_P{}^2\, T_A + (T_L + T_F)^2\, T_R + (T_J - T_L - T_F)^2\, T_D\}/(T_A + T_R + T_D)]}$$ [N/m] **(3.3)**

3.2.3 Speed Range

Speed range is the limit or speed that needed to drive or run the application and is determined by the type of application. High operating speed can be accounted for the components of trapezoidal speed curve, it give an average speed equal to the movement speed [4]. The curve is shown in figure 10.

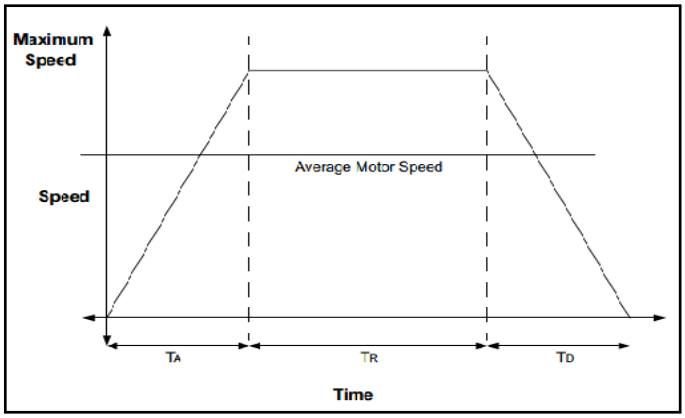

Figure 3.1: Trapezoidal Speed Curve [4]

3.3 Efficiency

Efficiency is defined as the ratio of output power and input power.

$$\eta = \frac{P_{Out}}{P_{In}} \quad \textbf{(3.4)}$$

Where $P_{In} = mVI$ and $P_{Out} = T_{load}\,\omega_r$

In term of power flow,

$$P_{In} = P_{cu} + P_{Fe} + P_{mec} + P_{out} \text{ [watt]} \quad \textbf{(3.5)}$$

Where $P_{cu} = mRI^2$ is the copper loss due to winding resistance, P_{Fe} the iron loss due to hysteresis and eddy current, and P_{mec} the mechanical loss due to windage and friction [3].

3.4 Torque-Speed Characteristic

The torque-speed characteristic of the motors referred to as permanent magnet, it is either brushless or brushed, and it either ac or dc shunt motor. The current that flow in the motor armature, and the magnetic flux that the armature is exposed to, is the cause for torque and motion. From this method, it can know that the behavior of torque is also depends on the current and voltage also.

The motion of the armature wires within the magnetic flux creates a back electromotive force (voltage). At slow speeds the back emf produced by the rotor is also low and high current result to high torque. At high speed the back emf produced is high and low current only can flow through. Low torque produced when the speed is high. In figure 11 is the typical torque-speed characteristic of motor.

The torque-speed curves can be expressed as an equation for linear torque characteristic:

$$T = T_S - k_m \omega \qquad [N/m]$$

Where:

Ts is the stall torque (provided in motor specifications)

k_m Is the slope curve

ω Is the rotating speed

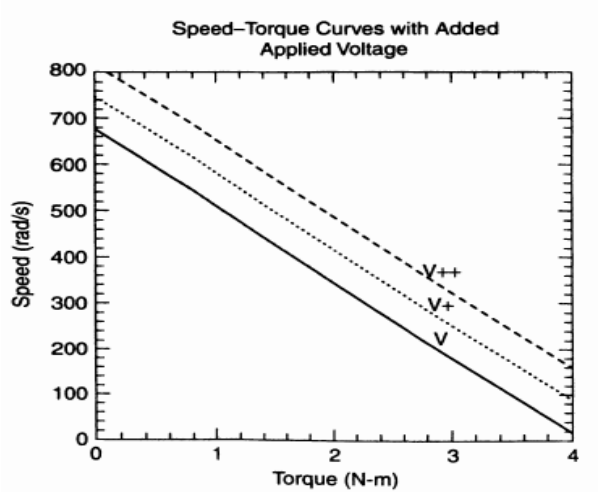

Figure 3.2: Typical Torque-Speed characteristic of the motor [12]

3.5 Conclusion

From this chapter, it can be conclude that the BLDC motor characteristic analysis are necessary to be done, so that the specification of the motor to be choose for the electric bicycle is compatible with the purpose of the electric bicycle will be used. By the way, method to done the analysis also must be conducted before analysis been done, this because, it important to know what must be analyze and what is need to be calculate.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter discusses the results, finding and the analysis of the project. The result of this chapter is related to the chapter 3, all the method that used in this chapter was stated in chapter 3. Result of this chapter was included the theoretical analysis which based on the assumption and calculation. Then, the analysis based on the journal also been done in this chapter by using software. The result of analysis then validated with the result in the journal. The outcome of this research will be discussed in detail by the next topic.

4.2 RESULTS AND FINDINGS

The Brushless DC motor was used to assist the Electric Bicycle to move in certain state. The BLDC was suitable for the purpose of the electric bicycle to be used.

4.2.1 BLDC Motor Torque

The torque for the BLDC is based on the theoretical analysis.

Torque, $\tau = F \times r$ (4.1)

Force, F = Mass, m x Acceleration, a (4.2)

Assume that:

Mass of Bicycle: 15 kg

Mass of rider: 70 kg

Angular Velocity, $\omega = 36.617$ rad/s

Distance traveled: 200 m

Acceleration, $a = 9.81$ m/s²

Maximum weight = 135 kg

Current, I = 13.89A

Voltage, V = 36V

4.2.1.1 Torque and Force Calculation

Force and torque applied on the electric bicycle without load

By using equation (4.1) and (4.2)

F = mass x acceleration (no-load)

= (15 kg) x (9.81 m/s²)

= 147.15 N

Then, the torque for the motor is:

No-load torque

τ = Force, F x Distance, D

= (147.15 N) x (200 m)

= 29 430 N.m

The weight of the bicycle and all of the part that embedded in the bicycle was taken calculate, so that the, force and the torque without any load or rider for the motor to produce can be acquired. This is because, it is needed to know that how much the torque and force required when there is no load applied on the bicycle, it required for purpose of initial or minimum force and torque required to move the bicycle.

Force and Torque with weight of rider

F = mass x Acceleration (with-load)

= (85 kg) x (9.81m/s^2)

= 833.85 N

τ = Force, F x Distance, D

τ = (833.85 N) x (200 m)

= 166, 770 N.m

It is necessary to find force and torque when load are applied on the electric bicycle. It is to analyze how much the torque and force needed by the motor to move the bicycle with certain mass and distance. This is because, this purpose is to find out and analyze the specific torque and force towards the specific aspect that were stated by using experimental theory.

Maximum Force and Torque

F = mass x Acceleration (Max weight)

= (135 kg) x (9.81 m/s^2)

= 1 324.35 N

τ = Force, F x Distance, D

= (1 324.35 N) x (200m)

= 264 870 N.m

Maximum force and torque that can apply on the motor and bicycle are very important to protect or know the limit of the motor capability in assist the electric bicycle to move. The maximum weight also must be stated in analysis; this is because when we talked about maximum, it means that, the limit of the motor to assist the bicycle in moving the maximum load.

4.2.2 BLDC Motor Power

BLDC motor is one of the type of motor that have efficient power production, that why it is selected in this project in order to assist the Electric Bicycle. In this sub topic, the power that produces by the motor are calculated in theoretical analysis method.

Stated that:

Power, P = Speed, v x Torque, τ

(4.3)

Maximum Speed for motor = 13 m/s

Assumption speed = 5 m/s

4.2.2.1 Power calculation using assumption speed.

Using equation (4.3)

Without load

Power, P = Speed, v x Torque, τ

= (5 m/s) x (29 430 N.m)

= 147 150 hp

With weight of rider and using equation (4.3)

With weight of rider

Power, P = Speed, v x Torque, τ

= (5 m/s) x (166, 770 N.m)

= 833 850 hp

= 833.85 khp

4.2.2.2 Power calculation by using maximum Load

Using equation (4.3)

Maximum Load

Power, P = Speed, v x Torque, τ

= (5 m/s) x (264 870 N.m)

= 1 324 350 hp

= 1 324.35 khp

Power that produced using assumption speed of 5 m/s was calculated. It show that the power that required for the motor to produce when different torque were applied on to the motor. From the assumption, the motor should have produced that kind of power when a specific speed applied on the motor.

4.2.2.3 Power calculation using maximum speed.

Using equation (4.3)

Without load

Power, P = Speed, v x Torque, τ

= (13 m/s) x (29 430 N.m)

= 382 590 hp

= 382.59 khp

With weight of rider:

Using equation (4.3)

With weight of rider

Power, P = Speed, v x Torque, τ

= (13 m/s) x (166, 770 N.m)

= 2 168 010 hp

= 2 1680.01 khp

Power calculation by using maximum torque:

Using equation (4.3)

Maximum Load

Power, P = Speed, v x Torque, τ

= (13 m/s) x (264 870 N.m)

= 3 443 310 hp

= 3 443.31 khp

The calculation above show the value of the power produced by the motor when maximum speed was applied toward the motor. The motor produce highest power when maximum torque and speed were applied on the motor. Hence, the maximum value of the power produce by the motor show that, the limit power that can be produce by the motor is 3 444.31 khp.

4.2.2.5 Angle of Slope versus Torque Analysis

Torque going up the slope	
Constant	
Force (N) =	147.15
Distance, D (m) =	200

Table 4.1: Constant value

From the table above, it show that force and distance used for going up the slope were keep constant, this purpose is to find out how much torque needed when going up different kind of slope.

Angle of the Slope, Θ	Torque, τ (N.m)
0	0
10	5110.465869
15	7617.044497
30	14715
45	20810.15257
60	25487.12763

Table 4.2: Angle of slope and Torque for the BLDC motor.

Table 4.2 show the value of the torque needed when going up the slope or when go through hill with different value of angle. This is about to proof that, high torques are needed when going up high slope. To calculate the value of the torque when going up the slope, this formula was use:

$$\tau = rF \sin \Theta \qquad (4.4)$$

Where:

F is force applied on the motor

r is distance traveled that going up the slope

Θ is angle of the slope.

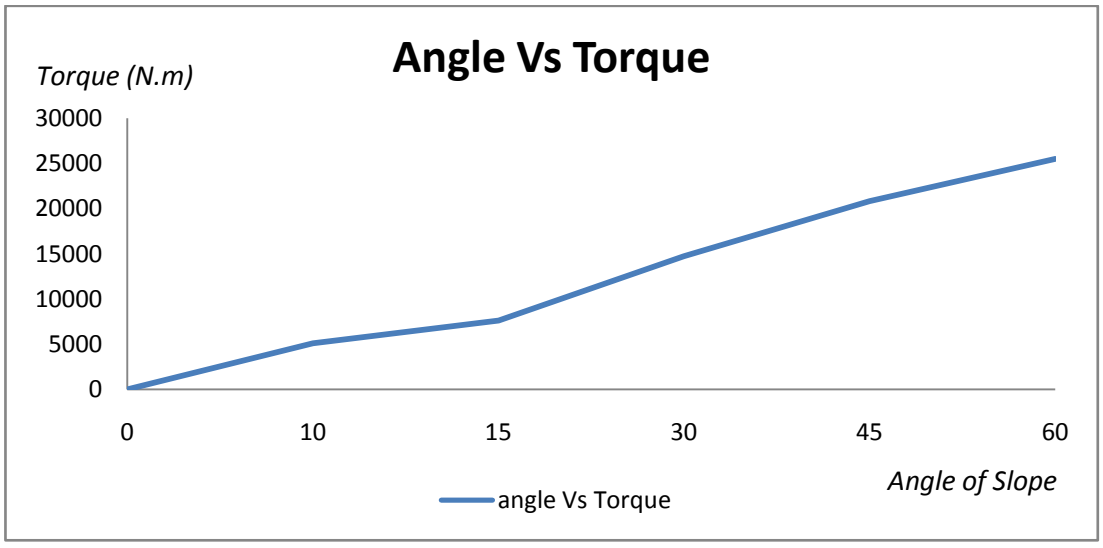

Figure 4.1: Angle of slope against Torque characteristic

Graphs 4.1 above show that, higher torque is needed when higher slope that go through by the bicycle. Even though force and distance used to going up the slope was constant, still higher torque needed to make sure the bicycle can manage to going up the slope. based on the graph 4.1, it can be seen that, at angle 15˚ and 10˚ does not have far differences uses of torque in order to going up the slope, it only slight increases of torque between both of the angle. From angle 30˚ up to 60˚, the increases of the torque are a bit larger. This is because the slope a steeper compare to angle at 10˚ and 15˚, higher torque are needed to manage the bicycle to going up the slope. Next, we look at angle 0˚ or flat road, the torque that needed near to zero because it does not have to go against the backward force that cause by slope angle. It only goes against the friction of the road.

4.3 Brushless DC Motor Analysis via MatLab

BLDC motor analysis was done by constructing the circuit for the BLDC motor that using permanent magnet, the circuit can be seen in Figure 12. By using matlab, there are three kind of characteristic was obtain, the graph is torque, speed and current of the Brushless DC motor. From this analysis also, some value of the BLDC produce was obtain. The values that were obtained are used with the equations stated in the Chapter 3.

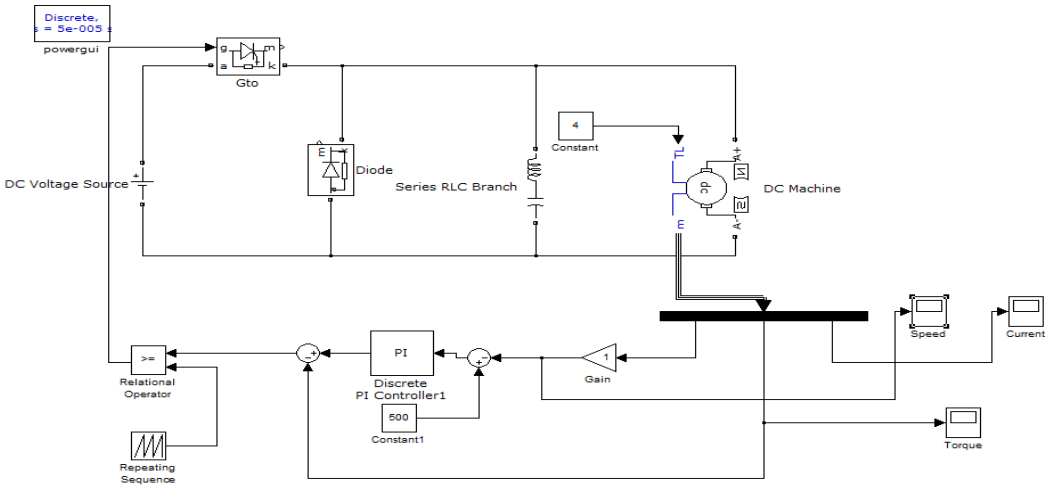

Figure 4.2: BLDC motor circuit

Circuit explanation

This circuit is for BLDC motor which is used permanent magnet. This motor operated by using 36V DC voltage source which based on the assumption above. The power supply for the circuit then connected to the Gate-take-off (GTO) thyristor which then connected to the diode and RLC branch in series. Constant which is four in values were connected to the Load torque of the motor; it means that load was applied on the motor. Then m port was connected to the data bus which connected to the scope and other components, like PI controller, Gain, and frequency oscillator.

4.3.1 Brushless DC motor speed by Matlab

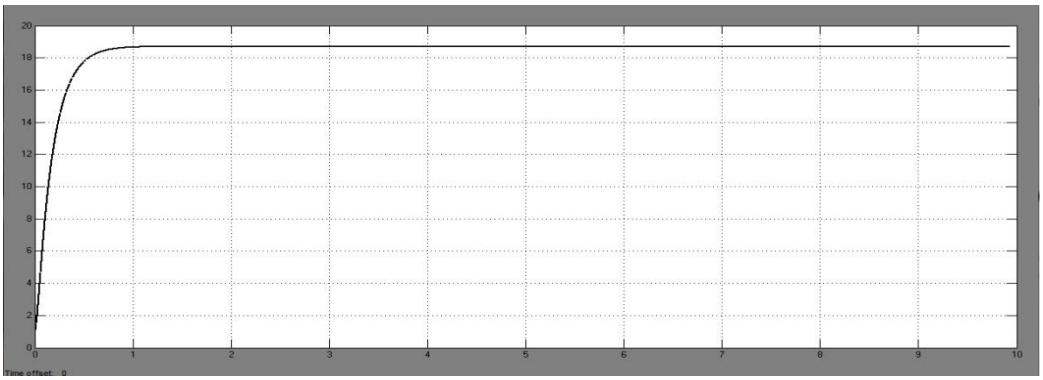

Figure 4.3: Speed (rad/s)

From the graph above, it can be used that to find the Root mean square torque

T_{RMS} of the motor.

We used the value of time:

$T_A = 1s, T_R = 7s, T_D = 2s$

T_A *Acceleration time*

T_R *Run Time*

T_D *Deceleration Time*

By using the formula that stated in the Chapter 3 before, the calculation was done as below.

$$T_{RMS} = \sqrt{[\{T_P{}^2\, T_A + (T_L + T_F)^2\, T_R + (T_J - T_L - T_F)^2\, T_D\}/(T_A + T_R + T_D)]}$$

$$T_{RMS} = \sqrt{[(6^2\,(1) + (4 + 0)^2\,(7) + (1 - 4 - 0)^2\,(2))/(1 + 7 + 2)]}$$

$$= \sqrt{\left[\frac{36+112+9}{10}\right]}$$

$$= \sqrt{\left[\frac{157}{10}\right]}$$

$$= \sqrt{15.7}$$

= 3.9623 N.m

From the calculation above which is based on the Graph and Data analysis using the graph, the T_{RMS} of the motor is 3.9623 N.m. This torque is depends on the value of the time for the motor to accelerate, T_A , Time for running, T_R and the time for the motor to decelerate, T_D . The main elements that influences the Root Mean Square torque is Peak Torque, $T_{P,}$ Load torque,T_L , Frictional Torque, T_F and Torque due to inertia, T_J .

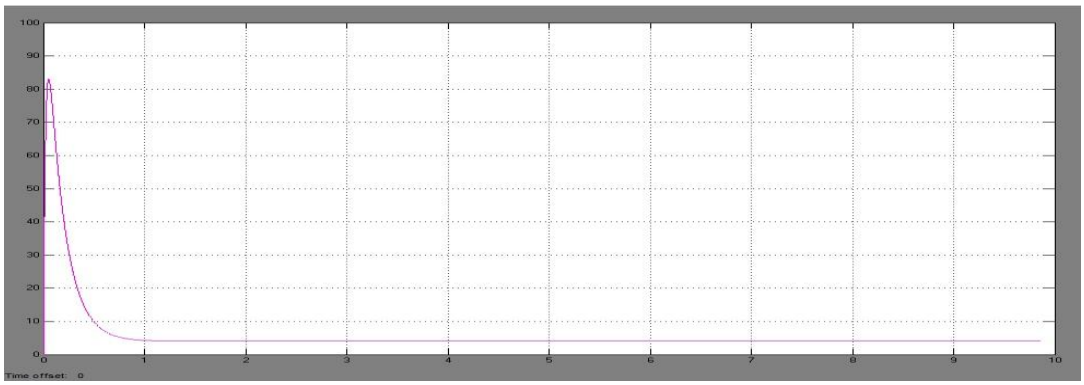

Figure 4.4: Current (A)

Graph in the Figure 4.4 above show the Current induced by the BLDC motor, the usage of the current for early or starting the motor is at maximum level, this is because at start up process, more current are needed to run the motor. After the motor has reach maximum current for start up, the voltage then gradually dropping

to lower current usage for the constant speed, the current then reach minimum current and reach constant value of current usage for the motor.

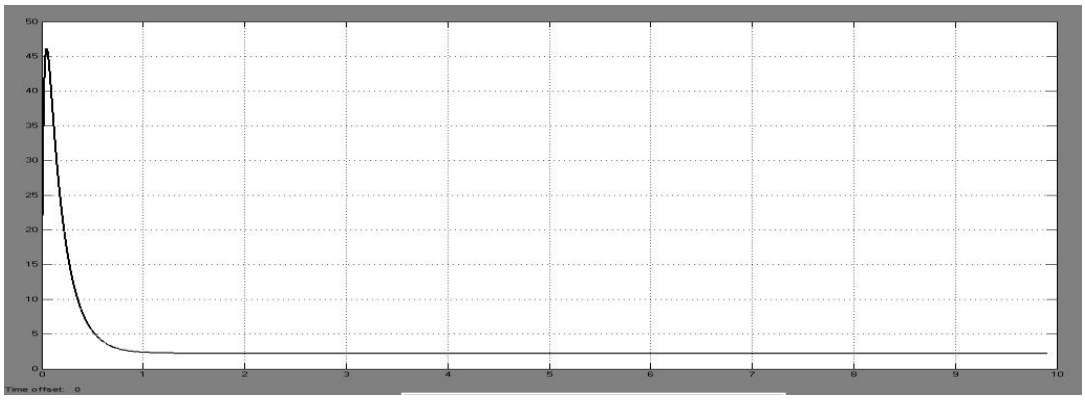

Figure 4.5: Torque (N-m)

Figure 4.5 above show the torque produce by the BLDC motor to move the electric bicycle. The torque gradually increasing to the maximum torque was caused by the start up process in order to move the bicycle; this is because torque needed to move the bicycle from rest is higher compared to the torque for bicycle that already moves. The torque produce then rapidly decrease, this because maximum torque produced by the BLDC motor is only to move the electric bicycle from rest, then, when the electric bicycle moving, high torque to not necessary anymore. This situation happen because torque needed were not used for the start up process anymore, the torque just need to make sure the electric bicycle that already moving to keep moving. These cases then make the torque produce by the BLDC motor which makes the bicycle move in constant torque.

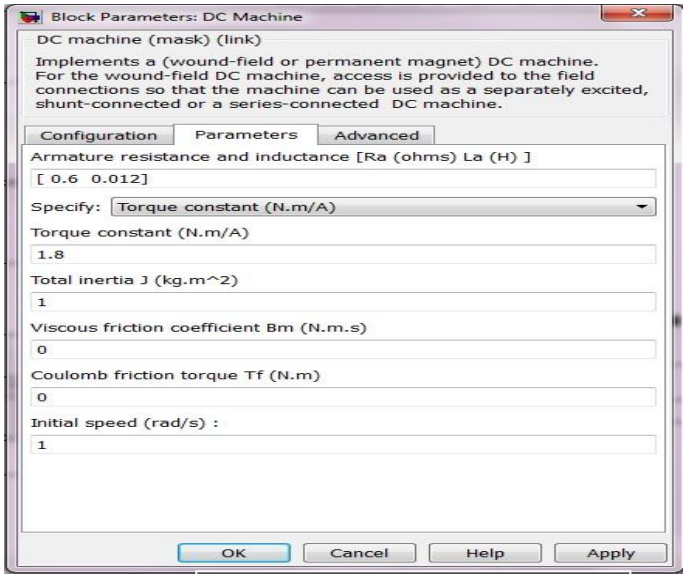

Figure 4.6: BLDC Motor Data

Figure 4.6 above show that the data or value in the motor, this value will be used as the value to find the Peak torque, T_P of the BLDC motor. By the way, this value show the value of the BLDC motor inner part, for the example total inertia, this value produce by the rotor of the BLDC motor. The initial speed shown in the figure 4.6 is the speed for the starting point of the electric bicycle, that means the rotor rotate with initial value of speed of 1 rad/s.

From the data in the Figure 4.1 and Figure 4.6 above, it is stated that the value of:

T_L = 4 N.m, T_J = 2 N.m, T_F = 0 N.m

By using equation 3.1 in the chapter 3:

$T_P = (T_L + T_J + T_F)*1.2$

$T_P = (4 + 1 + 0)*1.2$

$= 5(1.2)$

$= 6.0$ N.m

4.3.2 Power Calculation based on analysis data in Matlab

Using the equation in the Chapter 3, the power that will be considered in this chapter is:

$P_{In} = VI$ and $P_{Out} = T_{load}\,\omega_r$

Where

V is voltage

I is the current

T_{load} is the load torque needed by the motor

ω_r is rotational speed of motor

The value of the value above is:

V= 36V, I = 5A, T_{load} = 4 N.m, ω_r = 18 rad/s

Input Power, P_{In}

$P_{In} = VI$

P_{In} = (36V) x (5A)

= 180 Watt

Output Power, P_{Out}

$P_{Out} = T_{load}\,\omega_r$

P_{Out} = (4N.m) x (18 rad/s)

= 74.4 Watt

4.3.3 Efficiency

The efficiency value can be determined based on the value of the input power and output power. By using the formula stated in Chapter 3.

$\eta = \frac{P_{Out}}{P_{In}}$ x 100%

Where:

P_{in} = 180 watt

P_{Out} = 74.4 watt

$\eta = \frac{74.4}{180}$ x 100%

= 41.33%

4.4 Data Validation

Based on the analysis result, the data that were obtain and acquired was almost the same and similar to the analysis that were done on the journal. The graph of the speed, torque, and current was in similar formed but with different value of the data, which is the data were due to the different of value setting on the circuit that were used and different value of axis that were set on the scope, but the main thing that were used as comparison or validation of this result is the characteristic of graph that were produced by the motor.

Firstly, the characteristic of the motor that were produced by the BLDC motor in the circuit that were designed in the Matlab was almost similar to the result that were acquired in by the author of the journal, the graph flow is gradually increasing at the beginning until the motor reach maximum speed and then the speed constant until the motor decelerate. The result that was obtained by the author of the journal can be seen in the Figure 4.7 below.

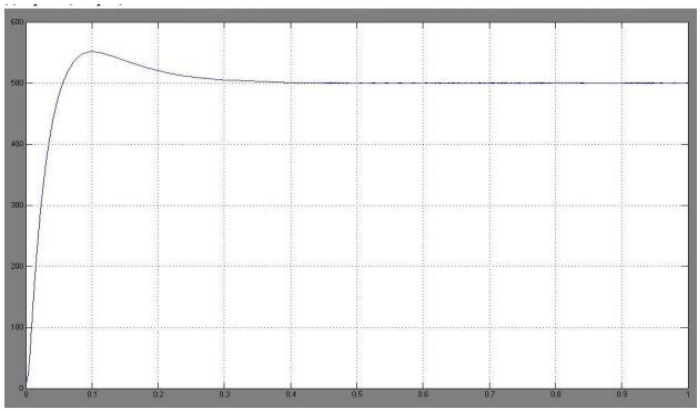

Figure 4.7: Reference Speed Result

Next is the current that consumed or used by the motor in order to move the electric bicycle. This current characteristic also similar to the analysis result that was done in Matlab also show the characteristic of the graph which is increasingly to the maximum current for the early process and dropping to the low current usage until the current constant. Figure 4.8 below show the current that were obtain by the author of the journal.

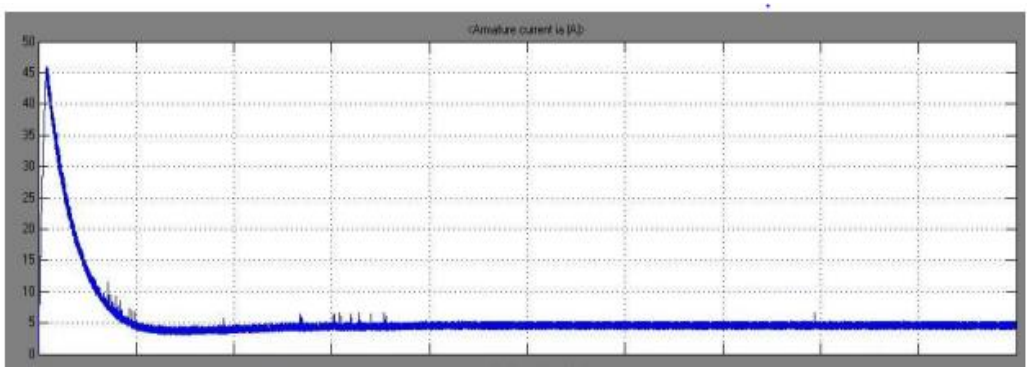

Figure 4.8: Reference Current Result

Also, the form of the torque that were obtained in the analysis also almost similar to the result in the journal, it also in form of rapidly increasing at the starting of the bicycle to start from rest, and start to decrease when the electric bicycle is decrease. Then the torque keep constant because of the bicycle in moving, small torque only needed to maintain the speed of the bicycle that were already moving.

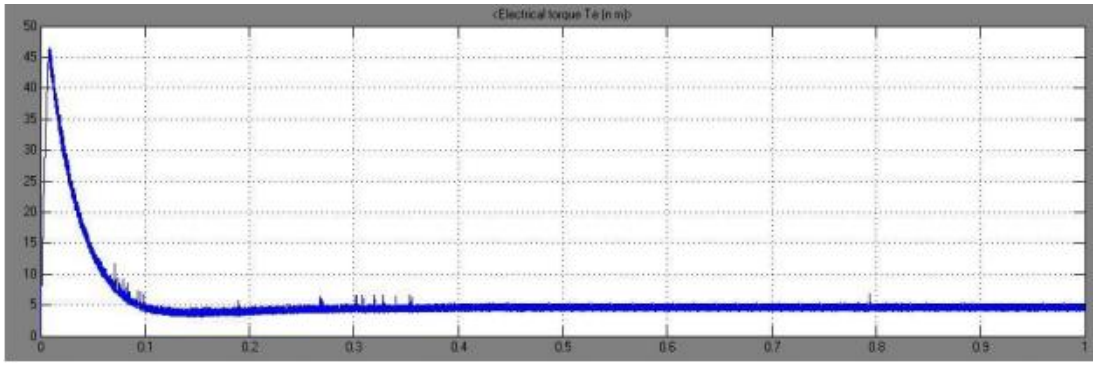

Figure 4.9: Reference Torque Result

4.5 Conclusion

The result that were obtain from the analysis show that the BLDC motor have high torque, constant speed, and have fast start up process which make the time for electric bicycle to move from rest is short. The theoretical analysis result yield a bit big value of torque, power, and force. This because, the results of this theoretical analysis are based on the assumption of the value of speed, forces, weight and distance travelled by the electric bicycle. For the analysis that done using software which Matlab, the analysis yield result that almost similar to the references. The torque, current and speed graph yield in the analysis difference because of the differences value of the constant. Then all the result are validated based on the journal that used as references.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter provides finding on this project. Future development and recommendation are noted as a topic in this chapter for enhancement of knowledge in continuing this analysis and research about the BLDC motor. Research that have been done also have a weakness or either mistakes. This because analysis just based on the software and assumption which not related with hardware.

5.2 CONCLUSION

From the result of this thesis, the torque yield by the BLDC motor show that the torque suitable to be used on the electric bicycle, this because the torque of the BLDC motor to move the electric bicycle increasing in faster rate in a split of second. The timing of the torque to rise at the early start up show that the BLDC motor have ability to move faster compared to other motor. Characteristic of the speed yield by the BLDC motor circuit show that the speed produces by the motor suitable for the electric bicycle optimum design.

This BLDC motor show that it has high power, even though the value of the torque used was small. It is necessary for electric bicycle to need high power to overcome any obstacle during moving. This happen because the usage of current from the BLDC motor, from the analysis it used only 5A to maintain in constant speed, this make the batteries of the electric bicycle can last longer. By validate the result of this analysis about the BLDC motor with the journal that used as reference, it is show that the analysis yield similar characteristic of torque, current and speed even though the value of the constant for each components are different.

Lastly, BLDC motor suitable to be used on the Electric Bicycle, this type of motor provides efficient speed, torque, and power to the electric bicycle. This type of motor should be used on the Electric Bicycle because this motor has many advantage compared to other DC motor, beside, this motor have lower percentage in context of maintenance probability because this motor not easily to break or become failure. From this, cost for maintenance can be lessening. Hence, BLDC motor is most suitable type of motor that should use on the electric bicycle.

5.3 Future Development

BLDC motor analysis shows that it has ability to provide high torque, speed and power with the uses of low current. From this analysis, it only show the BLDC motor ability in context of it speed, torque and power, this does not show the whole thing about the BLDC motor. Maybe, for the future development, I recommend that there is analysis or research about the copper loss for any type of motor which included BLDC motor, this because copper loss also one of the main element that make any motor either efficient or not to be used on the Electric bicycle.

By the way, research about the rotor and winding of the motor should be done, this because the rotor and winding of the motor play an important role in every type of the motor. Speed of the motor also depend on the rotor and winding, if the rotation of the rotor were slow or have failure on it, the speed of the motor also become a problem. This is why it recommended to do research about the copper loss, rotor and winding of the motor.

REFERENCE

[1] Robert, P. M., & Stephen Hagar, S. (1975). Electric bicycle. United States Patent, (381 447), 12-1,3,4.

[2] Michael A. , B. (2002). Electric bicycle transportation system. lntersociety Energy Conversion Engineering Conference (IECEC) , 37(20112), 739-737.

[3] Asher, R. (2004). Chapter 12. brushless dc motor. 48531 EMS,

[4] Padmaraja , Y. (2003). Brushless DC (BLDC) motor fundamentals. Stator, Rotor, 20-1,2,4,5. doi: DS00885A

[5] Tayloredge. (2010). hall element. hall theory,

[6] Wiberg, J. (2003). Controlling a brushless dc motor in a shift-by-wire system. Master's thesis performed in Vehicular Systems

[7] A., C., & C., E. (2004). Approach to decrease rotor iron losses of high speed or torque bldc motors. IRON LOSS DETERMINATION, doi: 0-7803-8486-5/04/$20.00 © 2004 IEEE

[8] A. , C., C., E., & N. , W. (2002). Bldc motor stator and rotor iron losses and thermal behavior based on lumped schemes and 3d fem analysis. IRON LOSSES DETERMINATION, doi: 0-7803-7420-7/02/$17.00 © 2002 IEEE

[9] SUN KO, J. (2010). Mrac load torque observer for position control of a brushless dc motor. International Journal of Electronics,

[10] G.H., Jang., J.H., Yeom., & M.G., Kim. (2006). Determination of torque–speed–current characteristics of a brushless dcmotor by utilizing back-emf of non-energized phase. Journal of Magnetism and Magnetic Materials 310 (2007) 2790–2792,

[11] Miroslav , M., Andre , H., & Yves , P. (2009). An analytical determination of the torque–speed and efficiency–speed characteristics of a bldc motor.

[12] C.Morchin, W., & Henry, O. (2006). Torque-speed characteristics. Electric Bicycles:A Guide To Design and Use, 121-118.

APPENDICES A

GANTT CHART / PROJECT SCHEDULE FOR FYP 1

FINAL YEAR PROJECT TITLE: OPTIMAL DESIGN ELECTRIC BICYCLE (ELECTRIC BICYCLE MOTOR)

WEEK / TASK	SEPTEMBER			OCTOBER				NOVEMBER				DECEMBER		
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Final Year Project Title Announcement & Briefing														
Project Title Research														
Project Objective & Project Scope Setting and With Supervisor														
Submission of Project Flow Chart & Gantt Chart for Supervisor Verification														
Project Introduction (Chapter 1) Writing & Submission														
Academic Research For Literature Review														
Literature Review (Chapter 2) Writing & Submission														
Project Analysis Identification														
Project Methodology (Chapter 3) Writing & Submission														
Complete Log Book Submission														
Final Year Project Mock Presentation														
Final Year Project 1 Presentation & Progress Report Submission														

GANTT CHART / PROJECT SCHEDULE FOR FYP 2

FINAL YEAR PROJECT TITLE: OPTIMAL DESIGN ELECTRIC BICYCLE (ELECTRIC BICYCLE MOTOR)

WEEK / TASK	FEBUARY		MARCH				APRIL				MAY				JUNE
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Finalize project Analysis Method															
Project Analysis Confirmation															
Analysis about the Motor															
Calculation based on assumption															
Analysis data collection															
Calculation Based on software analysis															
Data Validation															
Full Thesis Writing															
Complete Log Book Submission															
Final Year Project Mock Presentation															

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project in my own opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechatronic Engineering.

Signature :

Name of Supervisor : PROF. IR. DR. SHAH NOR BIN BASRI

Position :

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name : AHMAD ZAINUL ARIFFIN BIN MOHAMAD

ID Number : FB09031

Date :

Acknowledgments

In the name of Allah, the Most Gracious and the Most Merciful. Alhamdulillah, all praises to Allah, whom with His willing giving me the opportunity to complete this Final Year Project report. I am grateful and would like to express my sincere gratitude and appreciation to my supervisor, Professor Ir. Dr. Shah nor Bin Basri for his supervision and support. Supervision and support that he gave truly help the progression of this project.

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ABSTRACT

The creation of Electric Bicycle gives many advantages in our lives. This thesis is focused on the type of motor that used on the electric bicycle, the type of motor that were used on the electric bicycle is Brushless DC (BLDC) motor. The BLDC motor provides many advantages to the electric bicycle, it provide lots of benefits to the user. It is not only for electric bicycle it can be used to lot of machines. By the way, the characteristic of BLDC motor make it majorly being used around the world, this is because it has high efficiency, long life duration and more durable compared to other motor. The BLDC motor were widely been used on most type of the electric bicycle which is most compatible with it. The used of BLDC motor on the bicycle give the bicycle maximum performances and can travel longer with certain level. Analysis that was done to this type of motor is to determine either this motor suitable for the electric bicycle or vice versa. The criteria that were analyze are, torque, speed, power, current and efficiency.

ABSTRAK

Penciptaan basikal electrik memberikan banyak kelebihan dalam kehidupan kita. Tesis ini memberi tumpuan kepada jenis motor yang digunakan pada basikal elektrik, jenis motor yang digunakan pada basikal elektrik adalah berus DC motor (BLDC). Motor BLDC memberikan banyak kelebihan kepada basikal elektrik, ia memberi banyak faedah kepada pengguna. Ia bukan sahaja untuk basikal elektrik ia boleh digunakan untuk banyak mesin. Dengan cara ini, ciri-ciri BLDC motor membuat ia majorly digunakan di seluruh dunia, ini adalah kerana ia mempunyai kecekapan yang tinggi, tempoh hayat yang panjang dan lebih tahan lama berbanding motor lain. Motor BLDC secara meluas telah digunakan pada kebanyakan jenis basikal elektrik yang paling serasi dengannya. Pengunaan motor BLDC di basikal memberikan persembahan maksimum basikal dan boleh bergerak lebih jauh dengan tahap tertentu. Analisis yang telah dilakukan untuk jenis ini motor adalah untuk menentukan sama ada motor ini sesuai untuk basikal elektrik atau sebaliknya. Kriteria yang telah menganalisis adalah, tork, kelajuan, kuasa, arus dan kecekapan.

Dedicated to my Parents

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