Design and Analysis of 2 kW Induction Motor for Electric Motorcycle Application

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Abstract. The increase of demand in electrical vehicles initiates this research intending to reach high-performance electric motors applicable for motorcycles. The induction motor is chosen in this research because it causes low cost production, simple construction, easy maintenance, and easy speed control. In order to be directly applied widely, the dimensions of the motor are adjusted to the general size of an existing electric motorcycle chassis which imposes the motor size becomes compact with the consequence of efficiency decrease. Motor performance must also be reliable on all terrains, namely flat tracks, uphill and also reliable in transporting one or two passengers. An approach of the numerical method and performance simulation are carried out simultaneously. The design of the motor component is obtained by analytical calculations using MATLAB and performance analysis using ANSYS MAXWELL. The motor's speed, torque, and efficiency are analyzed to comply with the design requirements. Several changes such as the use of winding composition, slot type, and dimensional changes are taken into account and the results are analyzed in each track condition. The result shows the efficiency of the motor is 83.96% on a flat track and with one passenger. This is a good value of efficiency for a power rating of a 2 kW induction motor.

INTRODUCTION

Currently, electric motorcycles are getting more common in Indonesian market as the consequence of the government's desire to accelerate program of the Battery-Based Electric Vehicle Program through Regulation No. 55 of 2019. The electric motor as vehicle propulsion is one of the main components that require further development to increase the level of Domestic Content. One type of electric motor has been developed is induction motors. Induction motors have several advantages over other types of electric motors, including relatively cheap, have simple construction, easy to maintenance, and easy to speed control[1].

The design of this induction motor is adjusted to the general size of an existing electric motorcycle chassis which causes the motor size becomes compact and reduces the efficiency. The motor design of this project is customized and different from the dimensions and parts of conventional induction motors. The motor performance must also be reliable on all terrains, namely flat tracks, uphill and also reliable in transporting one or two passengers. Many changes are realized such as the use of winding composition, slot type, and dimensional changes and the results will be analyzed in each track condition[1,2]. The rotor slot type of the EV induction motor has large differences from the conventional induction motor in that it usually adopts a deep slot for better start-up characteristics, which will bring a large skin effect and increase the leakage resistance of the rotor. Moreover, it can also worsen the high-speed performance and reduce the efficiency and maximum torque[3].

This study aims to improve motorcycle performance following general electric motor design requirements as shown below

TABLE 1. *General Electric Motor Design Requirement*

Design Parameter	Value	Unit
Targeted Rated Power	2	kW
Targeted RPM motor	3800	Rpm
Targeted Wheel Torque	34	Nm
Battery voltage	72	VDC
Motor Dimension	160 x 164	mm

METHODOLOGY

A. Induction Motor Design Flow for Electric Motorcycle

In designing this induction motor, several stages must be done as shown in Figure 1. The design of the induction motor for this electric vehicle is to comply the needs or requirements of the electric vehicle.

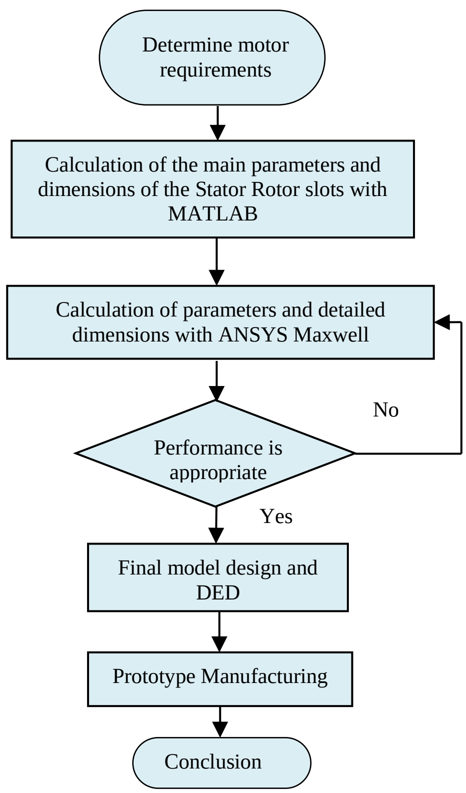


FIGURE 1. *Induction motor design flow*.

B. Detailed Electric Motor Design Requirement

The induction motors being developed must meet the requirements of existing electric motorcycles as follows:

- Can work using batteries with a capacity of 72 VDC and maximum current consumption of 60 A
- Stator outer diameter 140mm
- Laminate length 75mm
- Wire diameter meets size standards that do not complicate the manufacturing process
- Detailed requirements of this induction motor can be seen in the table below

TABLE 2. *Detailed Electric Motor Design Requirement*

Design Parameter	Road slope flat	Road slope 7'	Road slope 11'	Road slope 17'	Unit
Targeted vehicle speed	99	44	37	29	Km/h
Targeted RPM motor	5400	2400	2000	1600	Rpm
CASE A (Load 75kg or one passenger)					
Targeted wheel torque	13	15	18.5	20	Nm
Targeted motor torque	2.127	2.455	3.027	4	Nm
Targeted Power	1.2029	0.617	0.634	0.548	kW
CASE B (Load 150kg or two passengers)					
Targeted wheel torque	26	30	37	40	Nm
Targeted motor torque	4.2545	4.909	6.0545	6.5455	Nm
Targeted Power	2.41	1.234	1.268	1.0966	kW

C. Induction Motor Design Using MATLAB

Several equations are used to iterate on MATLAB. The first step is to determine the technical specifications of the motor, to get the parameters from the technical specifications there are some equations such as[4,5]

$$p = \frac{120\times f}{n} \tag{1}$$

$$I = \frac{P\times\sqrt{3}}{V\times cos\theta} \tag{2}$$

Where, $\boldsymbol{p}$ is pole, $\boldsymbol{f}$ is frequency, $\boldsymbol{n}$ is speed, $\boldsymbol{I}$ is electric current, $\boldsymbol{P}$ is motor power, $\boldsymbol{V}$ is voltage, $\boldsymbol{cos\theta}$ is power factor.

We have to consider the volume and size of the initial hole first, which is the basis of the whole design. This will affect other parameters of the motor. The following equation can be used to determine the diameter and length of the stator bore[6,7]

$$D_o = D_f - 2\times t_f \tag{3}$$

$$D = \frac{D_o-(0.647\times in)}{\left(1.175+\left(\frac{1.03}{p}\right)\right)D} \tag{4}$$

Where, $\boldsymbol{D_o}$ is stator outside diameter, $\boldsymbol{D_f}$ is outside frame diameter, $\boldsymbol{t_f}$ is frame thickness, **D** is stator bore diameter.

The volume of the stator and the size of the holes above are the beginning of designing the stator. However, the dimensional selection made is held outside the main iterative stator design process for determining the stator laminate, slot number, slot pitch, and conductor size as can be seen from this equation[6,8] .It can be determined from the following equation:

$$\mathrm{la}' = \frac{\mathrm{D^2 la}}{\mathrm{D^2}} \tag{5}$$

$$S_1 = p\times q\times m \tag{6}$$

$$\lambda = \frac{\pi\times D}{S_1} \tag{7}$$

$$\mathrm{s_{a1}} = \frac{\mathrm{I_1}}{\mathrm{a}\times\Delta_1} \tag{8}$$

Where, **la** is stator lamination, $\boldsymbol{S_1}$ is number of stator slots, $\boldsymbol{q}$ is integer variation stator slot number, $\boldsymbol{m}$ is motor phase, $\boldsymbol{\lambda}$ is stator slot pitch, $\mathbf{s_{a1}}$ is stator conductor size, $\mathbf{I_1}$ is full load current, $\boldsymbol{\Delta_1}$ is current density, **a** is circuit winding.

In designing the rotor to match the stator the hole casing is by the desired logic process, namely air gap sizing, number of rotor slots, and rotor slots per phase per pole[6].To determine the parameters in designing rotor, the equation is as follows:

$$D_r = D - (2 \times \delta) \quad (9)$$

$$S_2 = S_1 - 3 \quad (10)$$

$$N_{S2} = \frac{S_2}{m \times p} \quad (11)$$

Where, $\boldsymbol{D_r}$ is diameter rotor, $\boldsymbol{S_2}$ is number of rotor slots, $\boldsymbol{N_{S2}}$ is slot/pole/phase

D. Design of Induction Motor with Iteration Using RMxprt ANSYS Maxwell

After obtaining the main parameters and dimensions of the stator and rotor slots from the calculations in MATLAB, it is possible to iterate over the detailed parameters and detailed dimensions of the induction motor using ANSYS Maxwell. *RMxprt* is a template-based ANSYS design tool for electric motors that provides a quick analysis of motor performance and also creates 2-D or 3-D geometries to calculate the finite elements[9,10]. Here is the parameters to iterate on ANSYS Maxwell:

- Stator slot dimensions
- Number of conductors per slot
- Number of wires per conductor
- Wire diameter
- Dimensions of the rotor slots

Then in each of the above, the performance is simulated with eight-track conditions (according to table 2) in order to get performance and output power that meets the needs of the motor. The best performance results and meets the requirements listed in table 2 will be used as the basic design of the induction motor. After being simulated in ANSYS Maxwell, the design specifications for a 2 kW induction motor are as follows:

TABLE 3. *Induction Motor 2kW Specification*

Design Parameter	Value	Unit
Motor type	Induction	
Voltage	72 VDC	VDC
Rated Power (full speed with two passengers)	2.37	kW
Rated Speed (full speed with two passengers)	5402	Rpm
Rated Motor Torque (steepest slope with two passengers)	6.56	Nm
Number of poles	4	
Length	75	mm
Number of Stator Slots	24	
Outer Diameter of Stator	140	mm
Inner Diameter of Stator	87	mm
Stacking factor	0.95	
Number of Rotor Slots	21	
Outer Diameter of Rotor	85	mm
Air Gap	1	mm
Inner Diameter of Rotor	19	mm
Total Electrical Weight	7.45	Kg
Total Weight of induction motor	12	Kg

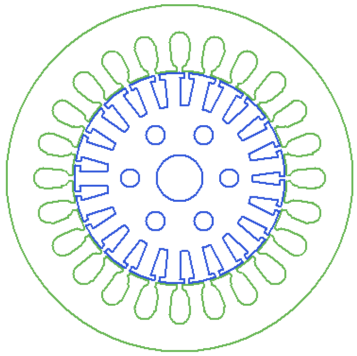


FIGURE 2. *View of stator and rotor structure in ANSYS Maxwell*

RESULTS AND DISCUSSION

Based on the methodology that has been carried out to obtain the induction motor design, the performance results are summarized in the table below. The simulation results show that the motor performance still meets the requirements. The highest-rated output power is 2.37 kW and the highest-rated speed is 5615.5 rpm on a flat track with one passenger. The highest-rated torque is 7.06Nm. The detailed curve of efficiency in each condition is shown in Figure 3

TABLE 4. *Result of Induction Motor Performance*

Design Parameter	Road slope flat	Road slope 7'	Road slope 11'	Road slope 17'	Unit
CASE A (Load 75kg or one passenger)					
Output Power	1.25	0.78	0.75	0.81	kW
Frequency	191	85	74	64	Hz
Rated speed	5615.5	2521	2195	1896	rpm
Rated Torque	2.12	2.96	3.26	4.08	Nm
Stator Phase Current	16.34	23.35	28.54	38.59	A
Efficiency	83.96	69.62	61.55	50.5	%
CASE B (Load 150kg or two passenger)					
Output Power	2.37	1.43	1.53	1.29	kW
Frequency	191	85	74	64	Hz
Rated speed	5402	2494	2166.6	1880.7	rpm
Rated Torque	4.18	5.48	6.74	7.06	Nm
Stator Phase Current	32.49	26.01	30.55	38.67	A
Efficiency	76.04	76.71	73	61.20	%

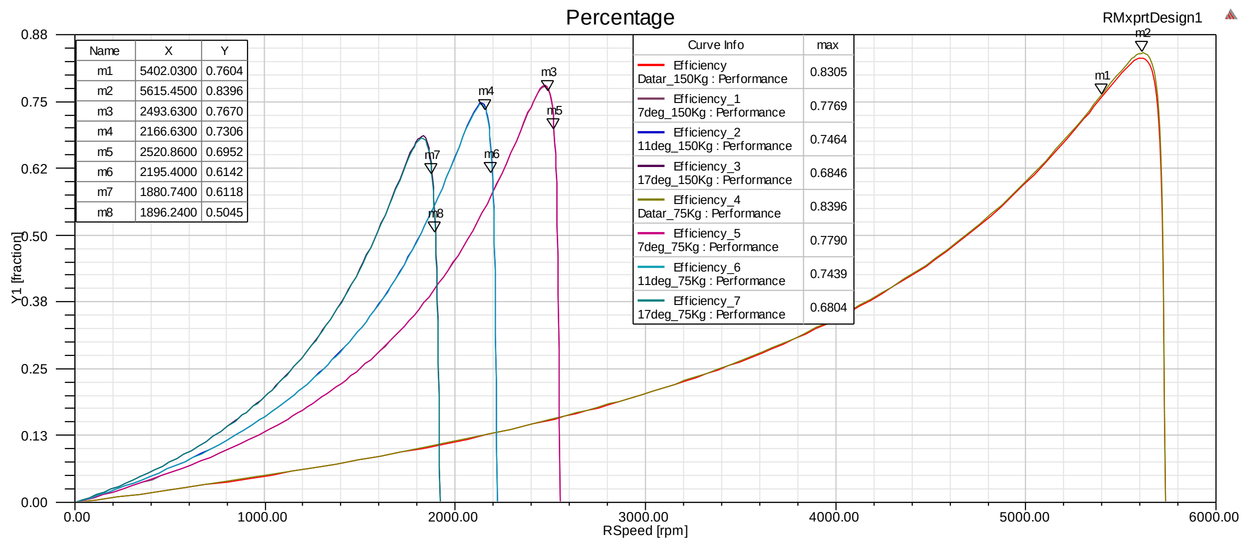
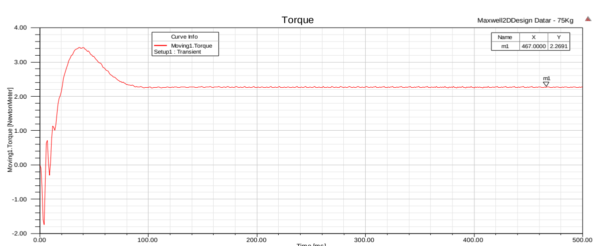


FIGURE 3. *The efficiency of motor depends on motor speed for eight condition (m1 = flat - load 150 kg, m2 = flat – load 75 kg, m3 = slope 7' – load 150 kg, m4 = slope 11' – load 150 kg, m5 = slope 7' – load 75 kg, m6 = slope 11' – load 75 kg, m7= slope 17' – load 150 kg, m8 = slope 17' – load 75 kg)*

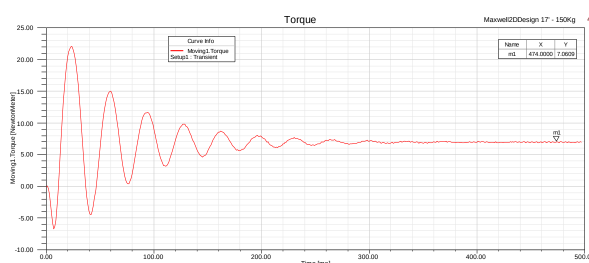
Table 4 and Figure 3 show the highest rated efficiency occurs on a flat track, which is 83.96% when one passenger rides. This is a good value of efficiency for a power rating of a 2 kW induction motor. Comparing the results in Table 4 with the target values in Table 2, It can be derived that almost all the target values have been met. The torque is the only parameter that does not meet the targeted value, yet its deviation is considerably small giving 0.1 Nm discrepancies. This shows that the design of this motor is already good enough to meet the performance in all track terrain conditions.

The curve of torque, winding current and flux density versus time on flat track with one passengers and on steepest track with two passengers is seen in figure 4 below.

a. Output Torque

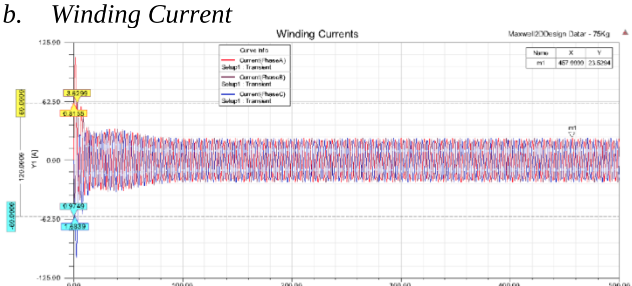


(a) Torque Curve on Flat Track with one passenger

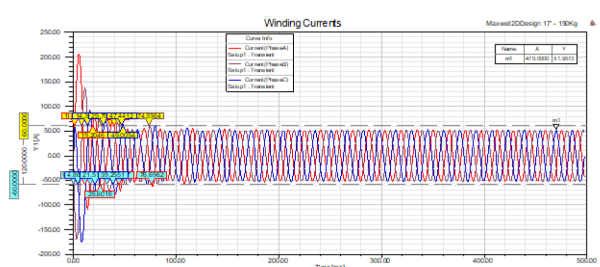


(b) Torque Curve on Steepest Track with two passenger

b. Winding Current

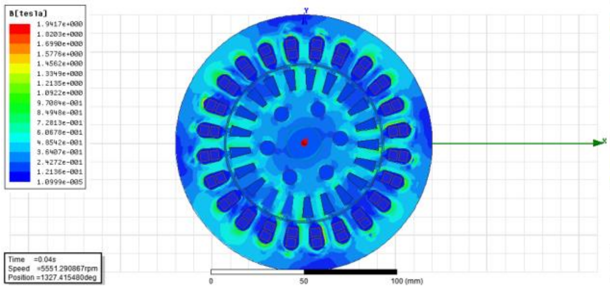


(a) Winding current Curve on Flat Track with one passenger

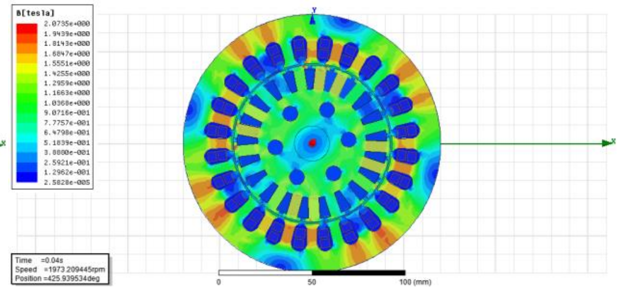


(b) Winding Curve on Steepest Track with two passenger

c. Flux Density



(a) Flux density digram on Flat Track with one passenger

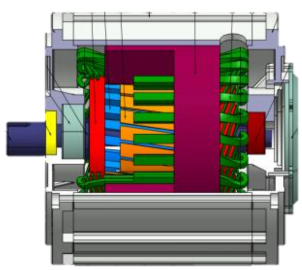


(b) Flux density diagram on Steepest Track with two passenger

FIGURE 4. *Torque Curve, Winding Current and Flux Density Curve on a Flat Track with One Passenger and on Steepest Track with two Passenger*

The torque curve shows that the torque is stable at 2.1 Nm starting from 100ms on a flat track with one passenger, and the torque is stable at 7.06 Nm starting from 400ms. The phase current stator curve shows that the stable curve at 23.5A starts from 100ms on a flat track with one passenger and the phase current stator curve is stable at 51.95A starting from 200ms. The flux density diagram shows that on flat track conditions the flux density is very small. It's different from the steepest track. This is because the smaller of frequency or RPM speed of the motor, the greater the required stator current, which will result in a greater flux density generated. This high flux density will cause a heat source when the motor is run. This shows that this design has stable performance.

After the performance simulation using ANSYS Maxwell is appropriate, the next step are the final model design, detailed engineering drawing (DED), prototype manufacturing and integration to existing platform as shown in figure below. As a recommendation to get the wheel torque 34Nm is using pulley with number of teeth 18:110.



(a) 3D Design

(b) Actual Prototype

(c)Prototype Integration into Platform

FIGURE 5. *Prototype of Induction Motor 2 kW*

CONCLUSION

In this design and simulation of the 2 kW induction motor, several changes such as the use of winding composition, slot type, and dimensional changes have been observed and the results have been analyzed in each track condition. The result shows the efficiency of the motor is 83.96% on a flat track and with one passenger. This is a good value of efficiency for a power rating of the 2 kW induction motor. Based on the result of the simulation, the highest-rated output power is 2.37 kW and the highest-rated speed is 5615.5 rpm on a flat track with one passenger. The highest-rated torque is 7.06Nm. As a recommendation to get the wheel torque 34Nm is using pulley with the number of teeth 18:110. The dimension of the prototype is very compact compared to a conventional induction motor 160 x 164mm. This induction motor design has fulfilled the design requirements for electric motorcycles.

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