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Analysis of in-Wheel Asynchronous Motor with Conical Geometry for Electric Vehicle

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ABSTRACT: The purpose of this study is to optimize the package geometry in wheel motors for an electric vehicle. In this context, it is aimed to analyze and design in-wheel asynchronous motor with a conical geometry for an electric vehicle. Thus, an asynchronous motor with a conical geometry and in-wheel asynchronous motor with a radial flux have been evaluated by comparing performance against each other within the package boundaries. An asynchronous motor design for the required performance requirements was realized by using the Ansys RMXprt program. The package analysis for the designed asynchronous motor was performed and the minimum and maximum package sizes for in-wheel asynchronous motor. The motor with conical geometry which is designed as a tapered geometry in 3D according to the minimum and maximum dimensions. In the Ansys Maxwell program, these 3 type motors were analyzed in terms of the rated torque, the rated revolution, the starting torque, the breakdown torque, the power factor, the efficiency and the magnetic flux on the rotor and the stator. It has been seen that every motor has advantages and disadvantages in the study. In this context, an asynchronous motor with a conical geometry may provide optimization for the desired properties.

Keywords: *Conical Motor, Finite Element Method, Electrical machines, Asynchronous motor, In-wheel motor*

1. Introduction

Electric vehicles are a concept that will contribute to the solution of both technical and economic problems. Certainly, electric vehicles will be a part of the transportation industry of the future. But most of the electric vehicles still make a great effort to get the cars in the sector (Baltatanu and Florea, 2015). Fuel consumption and eco-friendly product demands increase interest in clean energy and energy savings. In this context, hybrid electric vehicles emerge as a viable solution to meet their needs. There are many power transfer configurations for hybrid vehicles. The performance of hybrid vehicles depends on the integration of the power supply and the design of the powertrain (Al-Aawar and Arkadan, 2015). Electrical and hybrid electric vehicles are in great demand because of needing to improve the fuel economy and reduce CO2 emissions (Hua et al. 2015). Due to the increasing popularity of hybrids and electric vehicles, electric motorized traction systems have become widespread in the automotive industry (Chun et al. 2016).

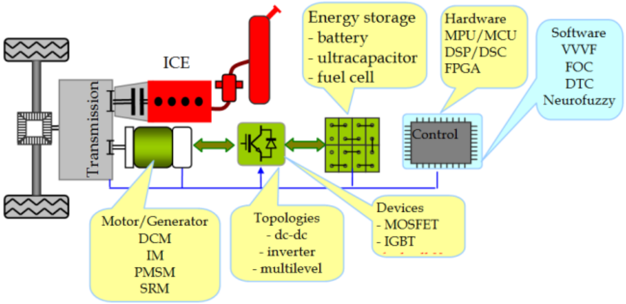

Figure 1. Electric Vehicle Configuration

Electric vehicles are seen as the most viable vehicle option for the future to reduce CO2 emissions, improve air quality, and reduce gasoline consumption. Basically, the feeling of using an electric vehicle is the same as a conventional internal combustion engine. Electric vehicles can provide up to 90% efficiency. The schematic and theoretical flow chain of EA technology is shown in Figure 1 (Shafiei and Carli, 2014).

1.1. Vehicle Dynamics

Since the ground vehicles are primarily designed to go in one direction, only the lateral dynamics in one dimension are considered. The lateral force is composed of 5 force components. These are inertia force, vehicle drag force, air friction, wheel friction resistance and gravity force. In Figure 2 the lateral force components are shown on a sloping path for a moving vehicle. Faero air friction, Froll rolling resistance and Fx traction force represents (Nam, 2010).

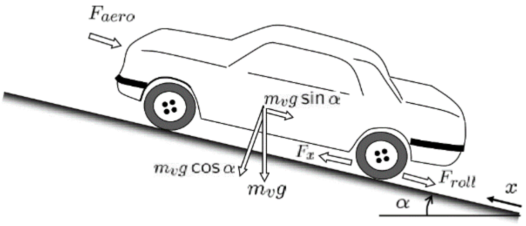

Figure 2. Lateral Forces on Vehicle Body

Where m is total mass of vehicle including passenger, Vx is vehicle speed, α is road gradient, g is gravity. In this direction, the traction force of a vehicle can be calculated by equation (1). (Nam, 2010).

$$F_x = m_v.\frac{d}{dt}.V_x + F_{aero} + F_{roll} + m_v.g.\sin\alpha \tag{1}$$

1.2. Asynchronous Motor Technology

There are 2 types induction motor. These are squirrel cage and wound rotor. In the squirrel cage, the stator windings are directly connected to the source, the rotor windings are placed outside the rotor with longitudinal bars and rotor bars are short-circuited with short-circuit bar. The wound rotor is similar to the squirrel cage except for the rotor bars. In wound rotor, rotor winding is made by isolation rotor winding. Squirrel cage induction motor is shown in Figure 3 (Bodson and Giri, 2013).

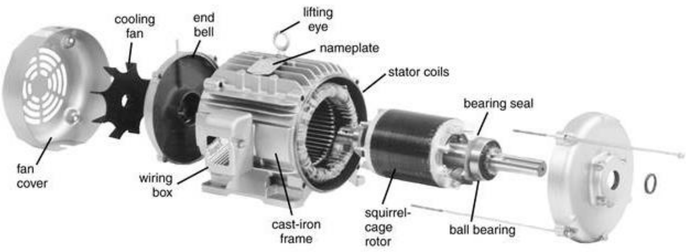

Figure 3. Motor Structure

An asynchronous motor is designed according to parameters of machine, performance, stator and rotor. In this study, design parameters are number of pole, input voltage, frequency, stator inner and outer diameter, motor length, number of stator slot, turn number, number of stator conductor, diameter of wire, diameter of shaft, number of rotor slot, height and width of rotor ring.

1.3. Vehicle Wheel

In this section, the standard dimensions of the vehicle wheels and the most commonly used vehicle wheel dimensions are investigated. An analysis of the standard car wheel size was carried out.

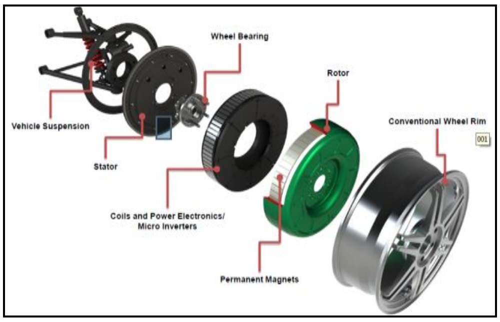

Figure 4: An Example for In-Wheel Motor

The details of in-wheel motor are shown in Figure 4. Three basic parameters have been investigated for wheel dimensions. These parameters are wheel outer diameter, rim size and wheel width. The design of the direct-drive asynchronous motor in this work is limited to the geometric dimension. This relates to the constraint or package volume, wheel width and rim size (Tire Size, 2017).

Figure 5: The Vehicle for Two-Passengers

1.4. The Characteristics of Electric Vehicle with Two-Passengers

Vehicle models for two-passenger electric vehicle were investigated and average vehicle parameter values were determined for doing calculations related to vehicle dynamics. The specified vehicle parameters are given in Table 1.

Table 1. Analysis Parameters of Vehicle Dynamics

Parameters	Value	Unit
Aerodynamic Friction Coefficient	0,3	-
AirMassDensity	1,2	kg/m3
Rolling Resistance	0,001	-
CurbWeight	375	kg
Accelearation (0-45km/h)	6	sec
Width of Tire	0,20	m
Diameter of Tire	0,56	m
Diameter of Wheel	0,33	m
Width of The Vehicle	1094	mm
Height of The Vehicle	1454	mm

The required performance values from the motor are calculated as in Table 2 as the result of the analysis for the parameters taking place in Table 1.

Table 2. Required Motor Performance Values

Starting Torque @ 10 deggrade	Rated Torque @ 1300 RPM	Breakdown Power
60Nm	10Nm	6,4 kW

2. Material and Methods

In this section, the design studies for the motor, which are necessary to reach the performance values shown in Table 2, have been performed. AnsysRMXprt program was used for achieving the desired motor performance values. Considering the wheel measurements given in Table 1, the maximum stator diameter must be 280 mm. Also, the motor length must not exceed 150 mm. 2D view of 3-phase asynchronous motor that can provide the values given in Table 1 is given in Figure 6.

The motor In Figure 6 was analysed according to the desired performance values. Therefore, the motor design parameters given in Table 3 are used to provide the desired performance values.

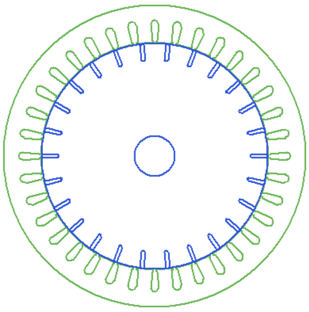

Figure 6. Asynchronous Motor with 280 mm Diameter and 150 mm Length

Table 3. Motor Design Parameters for Asynchronous Motor with 280 mm Diameter and 150 mm Length

Design Parameter	Value	Unit
Stator Outer Diameter	280	mm
Number of StatorSlot	36	-
Rotor Diameter	210	mm
Number of Rotor Slot	26	-
Shaft Diameter	38	mm
Rated Voltage	380	V
Frequency	50	Hz

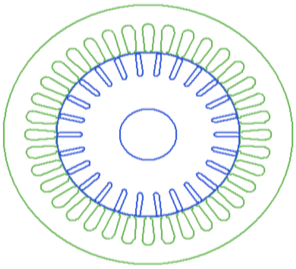

Figure 7. Asynchronous Motor with 190 mm Diameter and 150 mm Length

The smallest stator diameter that can provide the performance values shown in Table 2 should not be smaller than 190 mm. Otherwise, rotor flux density and stator flux density are saturated. To prevent this situation, saturation value for the material of M19_24G must be checked. Considering these restrictions, the 2D view for the asynchronous motor with a diameter of 190 mm is given in Figure7. Also Table 4 shows that the properties of the Asynchronous Motor with 190 mm Diameter and 150 mm Length.

Table 4. Motor Design Parameters for Asynchronous Motor with 190 mm Diameter and 150 mm Length

Design Parameter	Value	Unit
Stator Outer Dia.	190	mm
Number of Sta. Slot	36	-
Rotor Diameter	120	mm
Number of Rot. Slot	26	-
Shaft Diameter	38	mm
Rated Voltage	380	V
Frequency	50	Hz

3. Results and Discussion

The asynchronous motors shown in Figure 6 and Figure 7 were analysed. After the analysis, Torque-Speed curves and flux density results were obtained. These results show Figure 8, Figure 9, Table 5 and Table 6.

Figure 8 shows that Torque-Speed Curve for Asynchronous Motor with 280 mm Diameter and 150 mm Length. The obtained results from Figure 8 provide the desired performance value shown in Table 2. At the same time, Table 5 shows the flux density for Asynchronous Motor with 280 mm Diameter and 150 mm Length. These results shows the flux density for this motor is appropriate. It means the stator flux density value and rotor flux density does not reach saturation for the material of M19_24G.

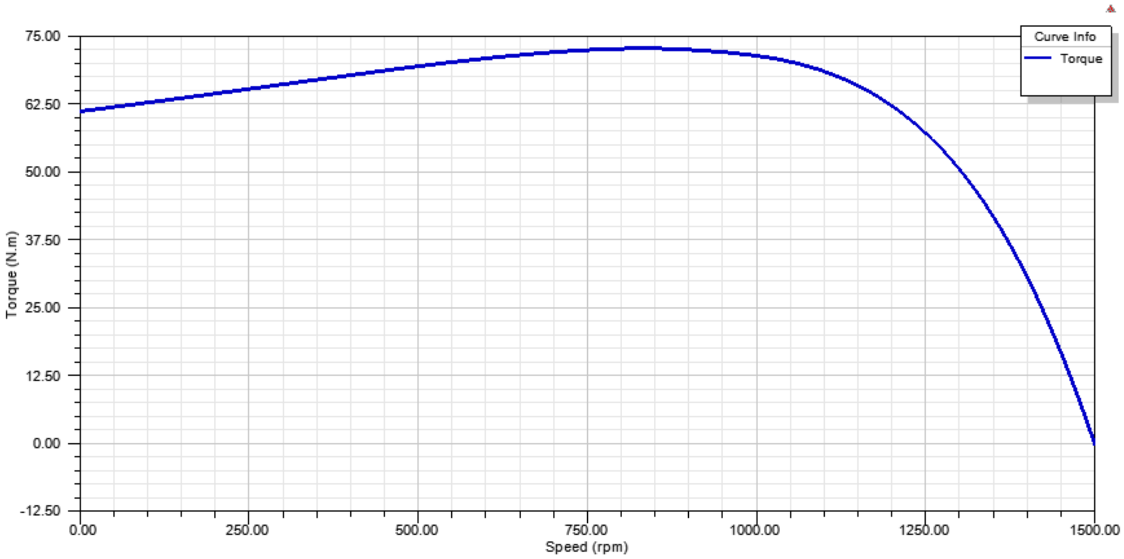

Figure 8. Torque-Speed Curve for Asynchronous Motor with 280 mm Diameter and 150 mm Length

Table 5. Flux Density Results for Asynchronous Motor with 280 mm Diameter and 150 mm Length

Design Parameter	Value	Unit
Stator Teeth Flux Density	0.625130	Tesla
Rotor Teeth Flux Density	0.569707	Tesla
Stator Yoke Flux Density	1.543530	Tesla
Rotor Yoke Flux Density	0.340659	Tesla
AirGap Flux Density	0.410718	Tesla

On the other hand, Figure 9 shows that Torque-Speed Curve for Asynchronous Motor with 190 mm Diameter and 150 mm Length. These results provide also the desired performance value shown in Table 2.

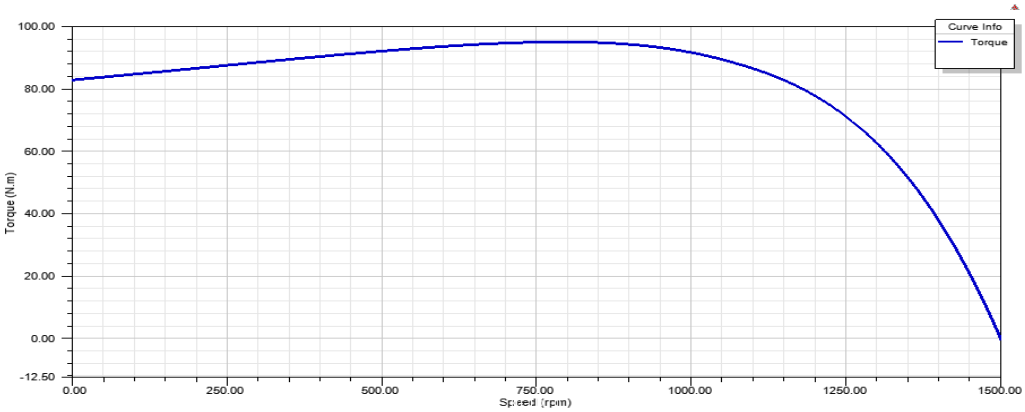

Figure 9. Torque-Speed Curve for Asynchronous Motor with 190mm Diameter and 150mm Length

Besides, the flux density results shown in Figure 6 are appropriate according to the design rules.

Table 6. Flux Density Results for Asynchronous Motor with 190 mm Diameter and 150 mm Length

Design Parameter	Value	Unit
Stator Teeth Flux Density	1.552970	Tesla
Rotor Teeth Flux Density	1.257470	Tesla
Stator Yoke Flux Density	1.625110	Tesla
Rotor Yoke Flux Density	1.020130	Tesla
AirGapFlux Density	0.717702	Tesla

Until this section, the motor designs have been developed in the minimum and maximum dimensions that will provide the desired performance values. Designed motors were analyzed and checked for their suitability. Here are 3D views of these motors. These 3D figures show the motors with the maximum dimension and minimum dimension.

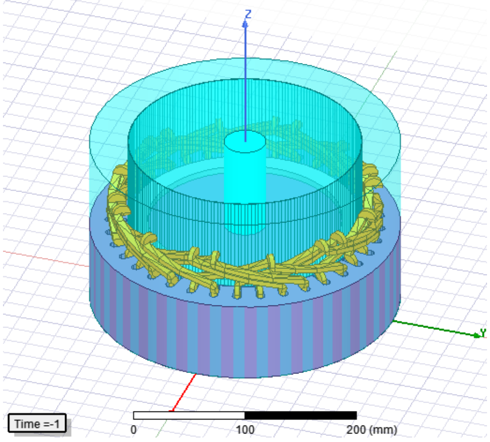

Figure 10. 3D View of 280 mm Diameter and 150 mm Length

Figure 10 and Figure 11 show that 3D views for the motor with 280 mm diameter and the motor with 190 mm diameter respectively.

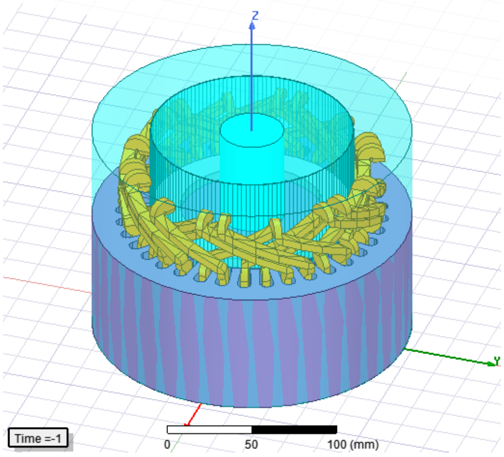

Figure 11. 3D View of 190 mm Diameter and 150 mm Length

The motor with conical geometry was derivated from Figure 10 and Figure 11. This conical motor is shown in Figure 12 the lower diameter of the conical motor is 190 mm and upper diameter of conical motor 280 mm the length of conical motor is 150 mm which is same with the motors shown in Figure 10 and Figure 11.

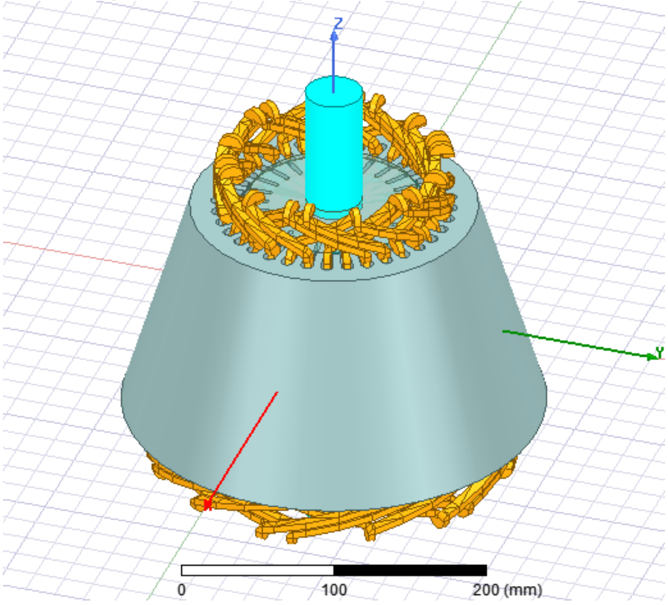

Figure 12. 3D Conical Motor View through 190 mm Diameter to 280 mm Diameter

This conical motor were analysed by Ansys Maxwell Program. Figure 13. shows Torque-Speed Curve of the conical motor. The obtained results from Figure13 provides the desired performance values shown in Table 2. Also, the power factor of the conical motor is 0.88831 and the efficiency of the conical motor is 75.3534%.

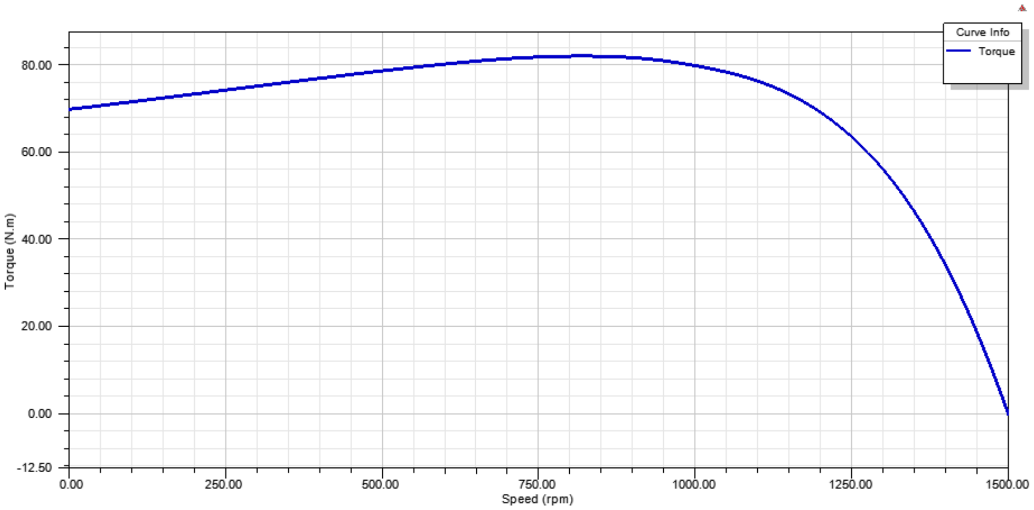

Figure 13. Torque-Speed Curve for Conical Motor

4. Conclusion

In this paper. Electric vehicles, vehicle dynamics and asynchronous motors were investigated. After the determining the vehicle requirements for two passengers, an asynchronous motor was designed. This motor was analysed to validate its suitability. Then, the smallest diameter for the motor that could provide this performance was analysed. Considering the dimensions of these two motors, a conical motor was designed and analysed. The results show that this conical motor meets the desired performance. At the same time, the analysis shows that the conical motor has improved power factor and efficiency. Besides, acceleration performance of the conical motor appears to be improving. It may be possible to achieve better performance values by optimizing the taper angle of this conical motor.

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