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Elektrikli Araçlar için Tekerlek içi Asenkron Motorun Performans Karakteristiğinin Hesaplanması

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ÖZET: Bu çalışmanın ana amacı elektrikli bir araç için tekerlek içi bir motorun tasarlanması ile ilgilidir. Bunun yanında, tasarlanan asenkron motor için geometrik optimizasyon çalışmaları ile maksimum performans elde edilmeye çalışılmıştır. Bu çalışmada, farklı geomerilerdeki asenkron motorların perfromans karakteristikleri ANSYS RMXprt programı kullanılarak incelenmiştir. İncelenen performans karakteristiğine ait parametreler anma devri, anma torku, yolalma torku, devrilme torku, güç faktörü, verim ve rotor ile stator üzerindeki manyetik akı yoğunlukları ile ilgilidir. Hibrit geometrili yeni bir motor modeli bu çalışmada önerilmiştir. Hesaplanan motor perfromansından elde edilen sonuçlar kullanılarak system perfromansı için enterpolasyon ile grafik oluşturulmuştur. Bu perfromans grafiği için bir eğilim çizgisi oluşturulmuştur. Motor perfromansı bu eğri üzerinden incelenmeye çalışılmıştır. Elde edilen bulugular, hibrit geometrili motorun daha iyi bir sonuç verdiği yönündedir. Dolayısıyla, bu durumu doğrulamak için bir kaç analiz daha yapılmıştır. Hibrit geometrili bu motor modeli tekerlek içinde limitli bir pakette optimize edildiği gösterilmiştir. Bu motor ile ilgili gelecek çalışmalarda ise solu elemanlar yönetimi ile 3 boyutlu platformda perfromans karakteristiğinin incelenmesi planlanmıştır.

Anahtar Kelimeler –*Elektrikli Araçlar, Elektrik Makinaları, Asenkron Motor, Tekerlek içi Motor*

Calculation of Performance Characteristic of In-Wheel Asynchronous Motor for Electric Vehicle

ABSTRACT: The main purpose of this study is regarding to design an in-wheel motor for an electric vehicle. Besides, the geometric optimization study of designed asynchronous motor has been realized to achieve maximum performance. In this study, performance characteristics of asynchronous motors in different geometric dimensions were investigated using the ANSYS RMXprt program. Investigated performance characteristics relate to rated revolution and rated torque, starting torque, breakdown torque, power factor, efficiency and magnetic flux on rotor and stator. A new motor model with hybrid geometry has been proposed. By using the results from calculating motor performance, an interpolation graph was created. A performance curve for this motor is fitted through the generated interpolation graph. The motor performance has been tried to investigate engine performance by this curve on interpolation graph. It is predicted that better results can be obtained a motor with hybrid geometry from the findings. Therefore, some analysis has been done to confirm the proposed model. This motor model with hybrid geometry has been shown to optimize the performance characteristics in a limited package on in-wheel motors. Future work for this motor with hybrid geometry has been planned to investigate performance characteristics on the 3D platform by using finite element method.

Keywords –*Electric vehicle, Electrical machines, Asynchronous motor, In-wheel motor*

1. Introduction

In these days, global warming is behind the main problems discussed all over the world. The research shows that global warming is also a result of fossil fuel consumption. Accordingly, the price of fossil fuels has increased from year to year (Ahmad et al. 2015). Global warming and energy crises have created the need to develop electric vehicle technology. It is predicted that the global demand for electric vehicles will grow very strongly by the activation of corporate average fuel-saving standards in 2016 (Sant et al. 2015). The use of electric motors as a part of efforts to prevent global warming and to reduce CO2 (carbon dioxide) emission has been accepted as a solution (Chiba et al. 2015). In today's world, electric vehicles are very interested in offering a solution to the concepts of energy and environment. Electric motorized traction systems offer wide torque-speed capability, high power density and high energy efficiency (Chen et al. 2015).

1.1 Electric Vehicle Technology

To reduce carbon dioxide emissions, improve air quality, and reduce gasoline consumption, the electric vehicles are seen as the most viable vehicle option for the future. Basically, the feeling of using an electric vehicle is the same as a conventional internal combustion engine. In general, the battery can use renewable energy resources for EV Technologies. Also, EV can provide up to 90% efficiency (Shafiei and Carli, 2014). The schematic and theoretical flow chain of EV technology is shown in Figure 1.

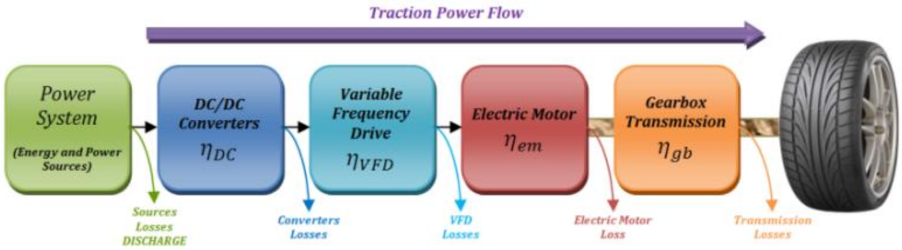

Figure 1: *The Structure of EV Technology*

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 2 (Bodson and Giri, 2013).

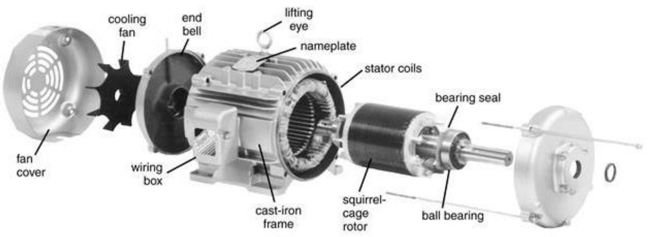

Figure 2: *Motor Structure*

The applied voltage to the phase inputs of the asynchronous motors allows a current to flow through the stator windings and thus a magnetic field. The rotation speed of this magnetic field is called synchronous speed. The equivalent circuit model of an asynchronous motor can be modelled as a transformer (Bodson and Giri, 2013).

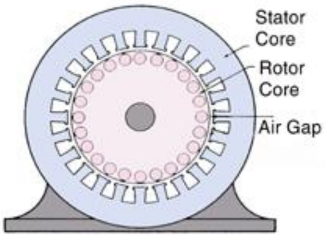

Figure 3: *The Cross-Sectional View of Induction Motor*

A cross-sectional view of an asynchronous motor is shown in Figure 3. And,Figure 3 shows that inner and outer diameter of stator, diameter of rotor, air gap distance, and slot geometry of rotor and stator. An asynchronous motor is designed according to parameters of machine, performance, stator and rotor. Where machine parameters are regarding to number of pole, friction-winding loss, and other loss factors. The performance parameters relates to output power, input voltage, output revolution-and torque, and the frequency of applied voltage. On the other hand, stator parameters contain the diameter of inner and outer of stator, motor length, number of slot, slot geometry, stator winding parameters. Rotor parameters are also similar to stator parameters.

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: *Vehicle Wheel Dimensions*

The parameters of vehicle wheel are shown in Figure 4. Three basic parameters have been investigated. 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 Calculator Website, 2017).

A wheel width of 8.9 inches and a rim diameter of about 17-18 inches are frequently used. From here, we can determine our boundary conditions by organizing our design parameters.

Table 1: *Different Geometric Dimensions for Stator and Rotor*

Experiment No	Stator Outer Diameter (mm)	Stator Inner Diameter (mm)	Rotor Diameter (mm)
1	330	210	209.2
2	320	200	199.2
3	310	190	189.2
4	300	180	179.2
5	290	170	169.2
6	280	160	159.2
7	270	150	149.2

2. Material and Methods

In this section, the geometric dimensions are analysed. A combination test sequence is shown in Table 1., in which only the motor stator external and internal diameter and rotor diameter are changed in the case of the motor parameters remain the same. The minimum permissible stator and rotor diameters from the stator and rotor slot geometries are limited to 270 mm to 149.2 mm respectively.

Table 2: *Performance Results for Motor Design Experiments*

Exp. No	Rated Torque (N.m):	Breakdown Torque (N.m):	Starting Torque (N.m):	Rated Revo. (RPM):	Efficy. (%):	Power Factor:
1	40	700	273	4490	79.53	0.28
2	40	704.5	283	4490	77.99	0.227
3	40	697.8	290.3	4489	75.38	0.177
4	40	663.8	290.9	4488	69.24	0.127
5	40	607.11	282.9	4486	60	0.102
6	40	548.23	271	4484	50.73	0.0927
7	40	485.15	255.3	4480	42.04	0.0898

When the analysis of motors with different geometric constructions given in Table 1. is carried out in RMXprt, the results are as in Table 2. and Table 3.

***Table 3**: Flux Density Results for Motor Design Experiments*

Exp. No	Stator Teeth Flux Density (Tesla):	Rotor Teeth Flux Density (Tesla):	Stator Yoke Flux Density (Tesla):	Rotor Yoke Flux Density (Tesla):	Airgap Flux Density (Tesla):
1	1.56226	1.22981	1.84697	0.602245	0.706256
2	1.72835	1.33062	1.85565	0.671569	0.740919
3	1.89783	1.4224	1.819	0.739579	0.764512
4	2.05194	1.48787	1.73035	0.802625	0.767656
5	2.21374	1.53951	1.61179	0.870193	0.75712
6	2.41268	1.58878	1.47871	0.95488	0.738019
7	2.68559	1.64165	1.3366	1.07363	0.711567

3. Results and Discussion

Considering the data in Table 2.-3., the 1.5 Tesla saturation value (BH Curve for M19 24 G used as Rotor and Stator Material) design shows that a suitable sizing option for the motor considered cannot be obtained. A new test sequence will be obtained when the smaller diameter in the geometry determined for the motor diameter in this direction is taken as 330 mm and the value for the larger diameter is determined as 390 mm. This test sequence is shown in Table 4. However, the values in Table 2. also indicate that the power factor is inappropriate.

***Table 4:** Different Geometric Dimensions for Stator and Rotor*

Experiment No	Stator Outer Diameter (mm)	Stator Inner Diameter (mm)	Rotor Diameter (mm)
1	330	210	209.2
2	340	220	219.2
3	350	230	229.2
4	360	240	239.2
5	370	250	249.2
6	380	260	259.2
7	390	270	269.2

In this respect, when the analysis of motors with different geometric constructions given in Table 4. is carried out in RMXprt, the results are as in Table 5. and Table 6.

Table 5: *Performance Results of Motor Design Experiments*

Exp. No	Rated Torque (N.m):	Breakdown Torque (N.m):	Starting Torque (N.m):	Rated Revo. (RPM):	Efficy. (%):	Power Factor:
1	40	700	273	4490	79.53	0.28
2	40	690	264	4490	80.09	0.32
3	40	679	255	4490	80.36	0.358
4	40	671	249	4490	80.49	0.37
5	40	662	243	4490	80.6	0.38
6	40	655	238	4490	80.72	0.387
7	40	647	233	4490	80.8	0.391

The results in Table 5. and Table 6. were improved according to previous analyses in terms of flux densities and power factor. However, the flux intensity and the power factor are absent in the desired situation.

Table 6: *Flux Density Results for Motor Design Experiments*

Exp. No	Stator Teeth Flux Density (Tesla):	Rotor Teeth Flux Density (Tesla):	Stator Yoke Flux Density (Tesla):	Rotor Yoke Flux Density (Tesla):	Airgap Flux Density (Tesla):
1	1.56226	1.22981	1.84697	0.602245	0.706256
2	1.47233	1.18093	1.82927	0.54274	0.696904
3	1.39463	1.13665	1.81994	0.495344	0.687198
4	1.31781	1.08898	1.82225	0.458114	0.67279
5	1.23372	1.03188	1.81939	0.424954	0.650058
6	1.15649	0.977615	1.81769	0.39644	0.62684
7	1.08673	0.927346	1.81638	0.37155	0.604231

A number of analyses are needed for this. First of all, try to improve the flux density without stator with the test chart in Table 7. to get the desired value.

Table 7: *Improved Test Table for Stator and Rotor*

Exp. No	Stator Outer Diameter (mm)	Stator Inner Diameter (mm)	Rotor Diameter (mm)
1	340	210	209.2
2	350	220	219.2
3	360	230	229.2
4	370	240	239.2
5	380	250	249.2
6	390	260	259.2
7	400	270	269.2

The results of the experiments in Table 7. are given in Table 8. and Table 9. The results from Table 8.andTable 9.were improved according to previous analyses in terms of flux densities and power factor. Table 8., which is needed in this case, is to bring the lower power factor to the desired level.

***Table 8:** Evaluation of Performance Results of Motor Design Experiments*

Exp. No	**Rated Torque (N.m):**	**Breakdown Torque (N.m):**	**Starting Torque (N.m):**	**Rated Rev. (RPM):**	**Efficy. (%):**	**Power Factor:**
1	40	684	257	4491	81.72	0.412
2	40	658	238	4491	82.11	0.495
3	40	634	222	4491	82.23	0.557
4	40	613	209	4491	82.4	0.601
5	40	596	200	4491	82.52	0.627
6	40	582	191	4491	82.61	0.645
7	40	570	184	4491	82.75	0.661

It is seen in studies of this division that the geometrical structure of the motor starts to grow from 330 mm solves the problem of saturation in flux densities. But it is impossible to improve the power factor by a single frequency control. For this reason, it is necessary to design the motor with input control voltage / frequency control. However, the desired starting torque and nominal torque are obtained in this way, at the same time the saturation reach of the flux densities is prevented and the desired power factor level is attained. It is also seen in the Taguchi method that the input voltage and frequency greatly affect the power factor.

***Table 9:** Evaluation Flux Density Results for Motor Design Experiments*

Exp. No	**Stator Teeth Flux Density (Tesla):**	**Rotor Teeth Flux Density (Tesla):**	**Stator Yoke Flux Density (Tesla):**	**Rotor Yoke Flux Density (Tesla):**	**Airgap Flux Density (Tesla):**
1	1.5978	1.25778	1.45709	0.619386	0.722323
2	1.49687	1.20061	1.44375	0.558424	0.708518
3	1.42171	1.15872	1.43477	0.509087	0.700541
4	1.34143	1.1085	1.42784	0.467954	0.684849
5	1.25735	1.05164	1.42488	0.433863	0.662508
6	1.18025	0.997699	1.42326	0.404671	0.639717
7	1.10963	0.94689	1.42305	0.37948	0.616965

Transient analyses were performed for the 7 different motors in Table 7. The motor model in which the transient analysis is performed is shown in Figure 5.

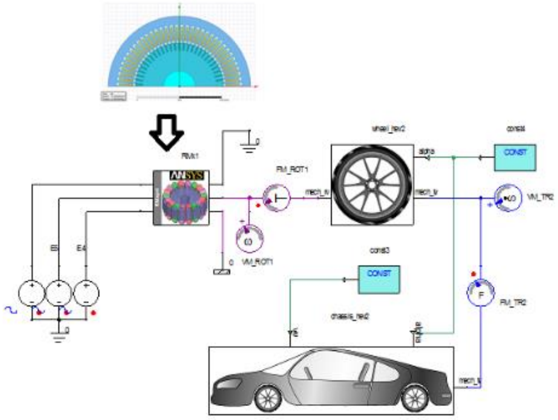

Figure 5: *Experimental Setup on ANSYS Simplorer for Transient Analysis*

Figure 6 and Figure 7. show that as the stator diameter increases, the acceleration and torque values decrease accordingly. These analyses were made for the motor-loaded condition and when the motor becomes stable, the ratedtorque is 40 Nm and breakdown torque is 500 Nm and starting torque is 260 Nm.

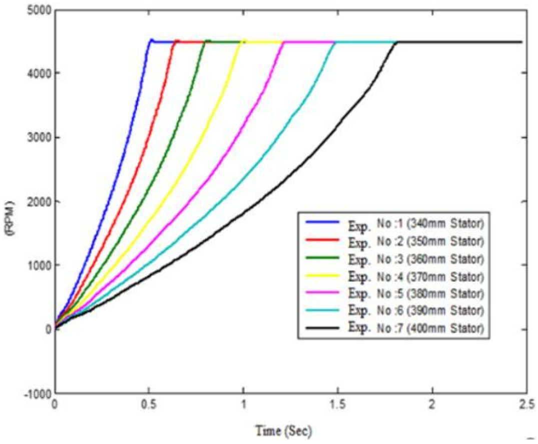

Figure 6: *RPM-Time Curves of Transient Analysis Results*

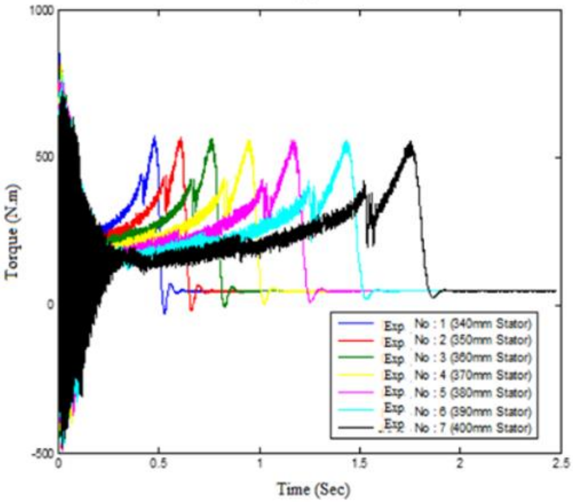

Figure 7: *Torque-Time Curves of Transient Analysis Results*

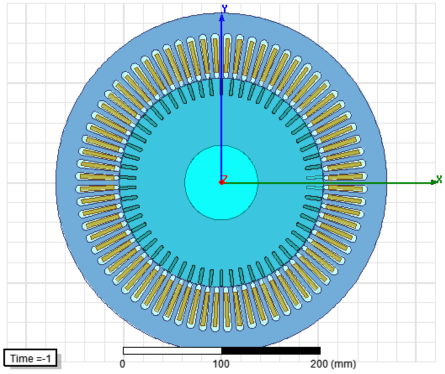

Figure 8:*The Cross-Sectional View of In-Wheel Motor*

The specified motors in Table 7 and Figure 8.are all radial flux motors. If the motor diameters given here are placed conically in such a way that the motor size is 200mm in total, the resulting image is as shown in Figure 9.

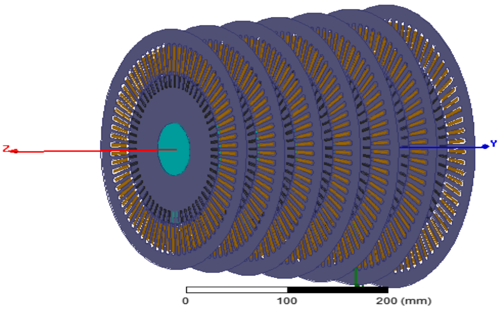

Figure 9: *The Proposed Model for In-Wheel Motor*

The length of all motor in Table 7 is 200mm.The produced torque by the radial flux motors is directly proportional to the length of the motor because of the equation (F=BIL). Therefore, considering the produced torque by a 200mm motor, the amount of torque per length can be found by calculating as torque / 200mm.Here, if the motor performance characteristics given in Table 8 are considered and the amount of torque per length is recalculated, the results are as in Table 10.

Table 10: *Performance Results per Length of the Motor*

Exp. No	**Rated Torque (N.m):**	**Breakdown Torque (N.m):**	**Starting Torque (N.m):**	**Rated Revolution (RPM):**
1	0,2	3,42	1,285	4491
2	0,2	3,29	1,19	4491
3	0,2	3,17	1,11	4491
4	0,2	3,065	1,045	4491
5	0,2	2,98	1	4491
6	0,2	2,91	0,955	4491
7	0,2	2,85	0,92	4491

In this section, the result in Table 10 are used for calculating the performance parameters for the new motor with hybrid geometry. While the results shown in Table 10 are easily calculated for the rated torque, the interpolation for the breakdown torque and the starting torque is required. These curve fitting operations are shown in Figure 10 and Figure 11.

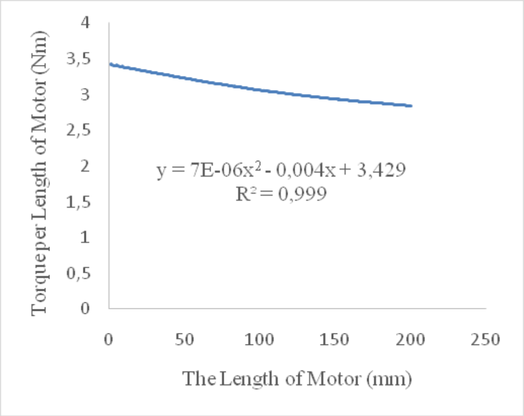

Figure 10: *Distribution for The Amount of Breakdown Torque on The Length*

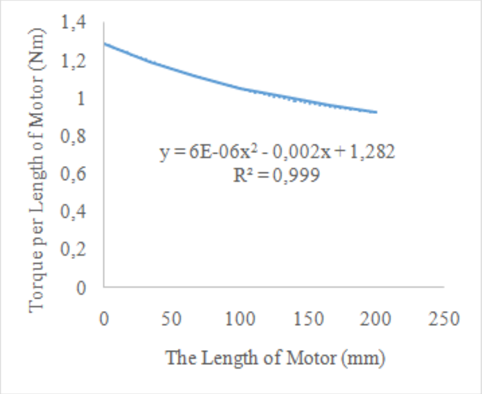

Figure 11: *Distribution for The Amount of Starting Torque on the Length*

Table 11. shows the motor performance results which are calculated from the torque per unit length for radiaxial motor.

Table 11: *Performance Results of Radiaxial Motor*

Exp. No	**Rated Torque (N.m):**	**Breakdown Torque (N.m):**	**Starting Torque (N.m):**	**Rated Revolution (RPM):**
Radiaxial Motor	40	618	214	4491

4. Conclusion

In this study, the performances of asynchronous motors in different sizes are investigated. The results have given the opportunity to develop a hybrid motor approach. And so, the motor model has been put forward. The interpolation method is used to derive the performance characteristics of this motor. A trend line was drawn for the graph obtained after interpolation and the motor performance was tried to be calculated. The obtained results in the calculations show that the performance characteristics of this proposed hybrid motor provide the desired values.

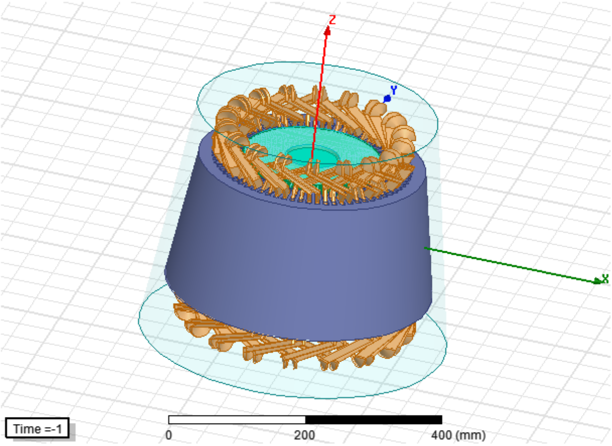

Figure 12: *The 3D Model for Radiaxial Motor on ANSYS Maxwell*

When the motor shown in Figure 9 is modelled as 3D, the model in Figure 12 is born. In future studies, transient analysis is planned to be performed with finite elements for3D model of proposed hybrid motor.

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