Design and Performance Test of Axial Halbach Brushless DC Motor with Power Density 1.5 Kw/Kg

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Abstract— **Progress of technology on electric vehicle component sector is one reason the emergence of electric vehicles at the moment. But there are still some shortcomings of this electric vehicle components, which is the low value of power density of existing electric motor in the market today. The final project was done making the design, simulation, and architecture of the Axial Halbach Brushless DC Motor. This final project generates Axial Halbach Brushless DC Motor with construction of one rotor and a stator. Axial DC Brushless Motor Halbach consists of 10 pole halbach magnet system permanent and 30 slot on the stator. On the performance test of Axial Halbach Brushless DC Motor of efficiency is obtained by 92.72%, power output of 807.34 Watts, torque of 2.24 Nm, moment rpm 3451. As well as the power density of 0.588 kW/kg at opening throttle 50%.**

Keywords— **Halbach Brushless DC Motor, Litz wire, architecture electric motor, electric motor performance test.**

I. PENDAHULUAN

Progress of technology on electric vehicle component sector is one reason the emergence of electric vehicles at the moment. Starting from battery which has a current density is great up to the automatic control systems on electric vehicles. Motor Brushless DC electric motor type is the most widely used as activator on electric vehicles. This is because the BLDC motor has several advantages compared with DC brush type motor or with AC type motor. Some of the advantages that is:

BLDC motor can use battery for the power source unlike on AC type motor.

Do not cause hot and noisy sounds like motor brush while working.

The design is fairly simple to installation on the vehicle.

Treatment is not necessary, because there is no friction between stator and rotor.

However in the application of DC brushless motor found some disadvantages that is:

Low Power at range 0,375-0,75 kW/kg

The emergence of cogging symptoms at low rpm caused by changes of attraction between the iron and magnet

Heat rising in the stator coil.

BLDC motor consists of two types, namely axial flux and radial flux. In class motor mover for electric vehicles, the use of axial flux quite compete with radial flux. With some of the profits on the type axial flux from a better heat dissipation, air gap can be arranged, as well as having a better torque compared to radial flux.

The power density of a mover is one of the factors that largely determine the level of efficiency of a vehicle. Where the higher power density of a driver, it will be the lower the fuel consumption of the vehicle is required. Such as an efficient competition namely the Shell Eco Marathon as well as Kontes Mobil Hemat Energi, where the value of power density has a very big effect on the outcome of the races. On that basis designed axial brushless DC motor with Halbach array magnets on the rotor and litz wire is used as the coil for the coreless stator. Because by using the concept of halbach array system a magnetic field can be deflected, so the use of iron plates as the rotor can be replaced with lighter materials. The use of litz wire as coil can minimize the heat arising on the stator due to internal resistance of the coil. Because litz wire itself is a parallel arrangement from a small diameter wire which has a very small internal resistance. As well as coreless stator systems with Faulhaber weaving method that aims to eliminate cogging which occurred as a result of the magnetic field in the stator which has not been separated if using an iron core. The use of selection methods on a weaving by using faulhaber coreless system is, because the distribution of weaving that can be optimized up to two crossed layers which having the same thicknes woven together in order to have a strong magnetic field with a total thickness of thin stator.

II. RESEARCH METHODOLOGY

In completing this final project, drafted a number of steps which are steps in realizing the goal. Stages are expressed in a flowchart as follows:

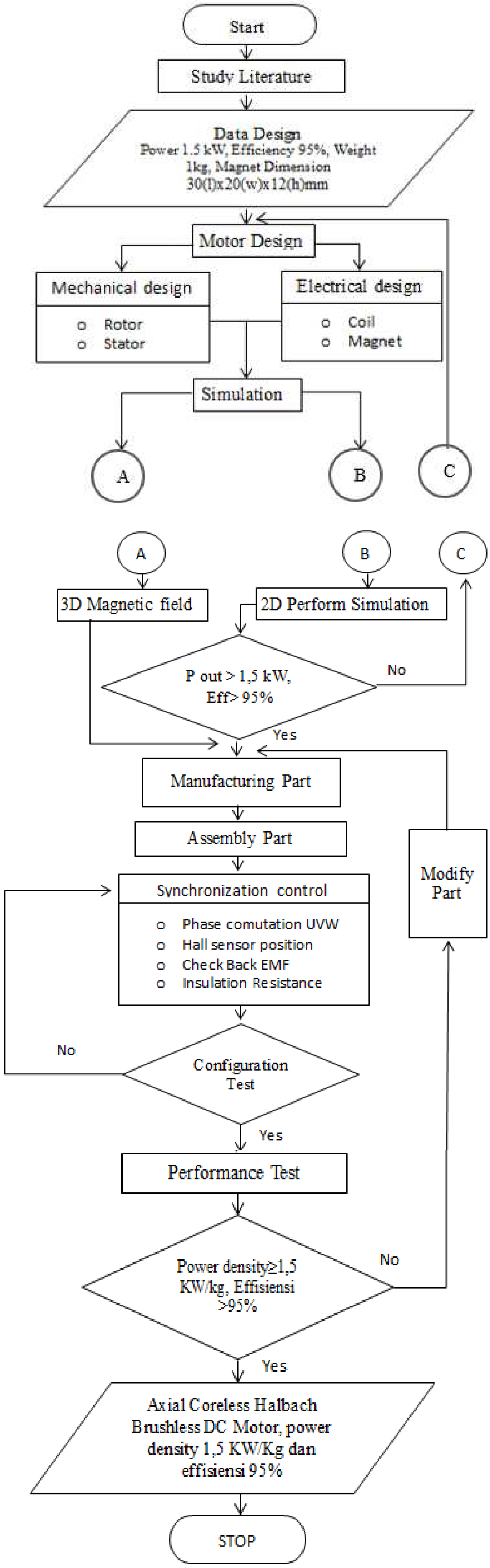

Figure 1. Final Project Flowchart of Design Axial Halbach BLDC Motor.

The methodology in this final project can be seen in the flow chart above. The initial step is to collect a wide variety of data both from theses, journal, book, or other sources that can help in the process of making this final work

The second step is designing mechanical and electrical design based on the target specifications.

The third step is the analysis through simulation either 3D or 2D by using finite element software.

The fourth step is the creation of prototypes. From manufacture to assembly all of its components.

The fifth step is checking the entire electrical components which mounted on the motor.

The sixth step is to test the configuration between the motor and the controller. Then sign in to the testing phase.

The final step of writing this final project is the withdrawal of the conclusions based on the data that has been analyzed and the giving of advice in it.

III. Result and Analysis

From this research obtained some data from either the results of the simulation as well as from the results of testing on Axial Halbach Brushless DC Motor.

A. Simulation

The results of 3D simulation on finite element software in the form on the direction of the magnetic flux and the flux density in the preparation of magnetic configuration with normal and halbach can be seen at the Figure 2.

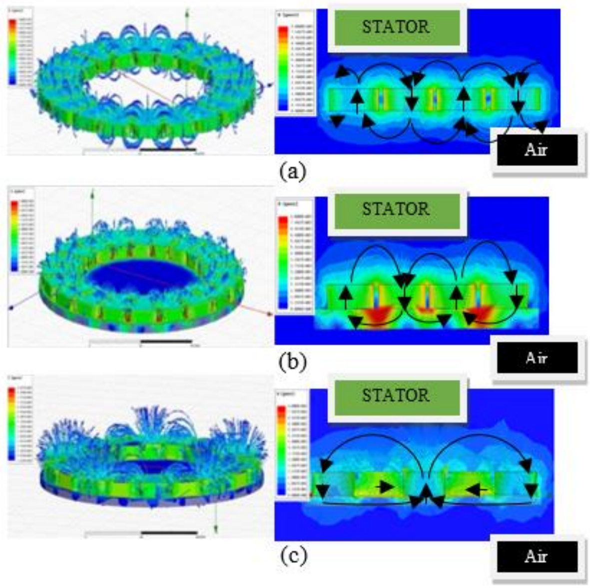

Figure 2. (a) Simulation result on normal configuration without iron backing plate, (b) Simulation result on normal configuration with iron backing plate, (c) Simulation result on halbach configuration with aluminium backing plate.

In Figure 2 (a), (b), and (c) shows how the direction and the flux density of magnet which is on each system that has been simulated. From Figure 2 (a) it can be seen how the direction and the magnetic flux density that occurs in normal magnetization system without the iron for its backing plate. The differences are quite noticeable when the normal system magnetization is given the iron for its backing plate as in Figure 2 (b). The flux density on the parts in contact with the supporting iron becomes smaller and flux density magnets that occurs in the magnet is not in contact with the supporting iron becomes higher compared with not using an iron crutch. This is because the iron material is used as the support to helps the magnet to deflect the magnetic flux. While in Figure 2 (c), shows how the flux density is greater on the side which is not contact with the aluminium supporting plate, but generate a little of the magnetic field on the side which in contact with the supporting plate though not using iron as a material for the supporting plate. This is because the magnet orientation on a horizontal pole of halbach magnetization systems replace the functions of iron in the rotor plate to divert the direction of magnetic flux, and also to encourage the magnetic flux on the side that facing the stato

From the 3D magnetic field simulation above, it can be drawn the conclusion that the magnetization with halbach magnet arrangment provides several advantages. There are the magnetic flux density generated greater than normal magnet configuration and also can replace the material for the supporting plate with other material than iron thereby minimizing the weight of the rotor. Which leads to increase the power density of electric motors.

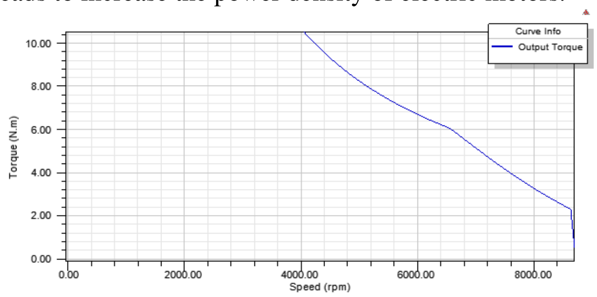

Figure 3. Torque Vs rpm.

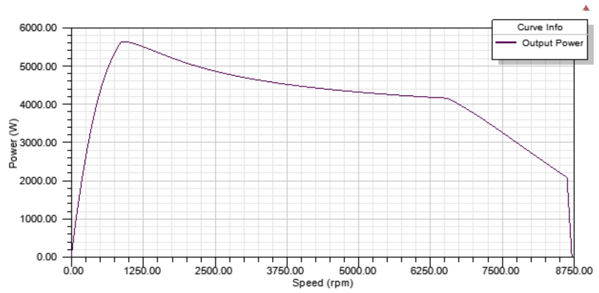

Figure 4. Power output Vs rpm.

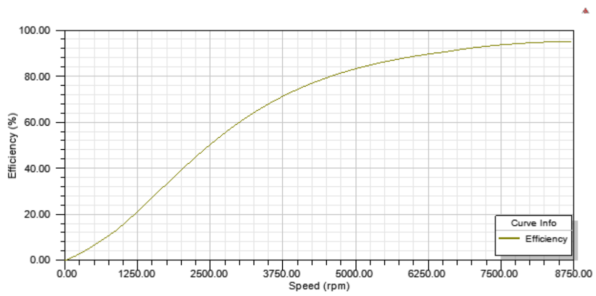

Figure 5. Efficiency Vs rpm.

In figure 3, it show the performance simulation of Axial Coreless Halbach BLDC Motor torque output values obtained of 2,27 Nm at rpm 8642,24. The value is the value of the rated motor torque, which means motor stable torque at speed 8642,24 rpm.

In figure 4 show output power at stable rpm is 2061,28 Watt. From this data it can be calculated the amount of efficiencies that are owned by Axial Coreless Halbach BLDC Motor. The efficiencies of Axial Coreless Halbach BLDC Motor can be calculated by the following equation:

$$\eta = \frac{P_{out}}{P_{in}} x\ 100\% \quad (1)$$

So we get the motor value of motor efficiency,

$$\eta = \frac{2061{,}28}{2167{,}97} x\ 100\% \quad (2)$$

$$\eta = 95{,}07\ \% \quad (3)$$

The efficiency value is mostly affected due to the losses contain in the armature copper loss which amounted to 50,04 Watt. Where the value of the large current produce great heat loss on Axial Coreless Halbach BLDC Motor.

B. Assembly Component

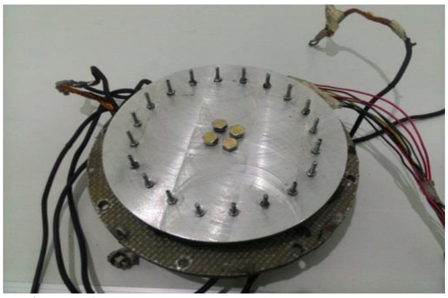

Figure 6. Axial Coreless Halbach BLDC Motor

After the simulation process is completed, the next process is entered into the stage of manufacture and assemby. For the step of assembly stage, consist of several steps:

- Litz wire coil that has been wound on the stator plate attached to the stator case using high temperatur eopxy that does not shift the position of the coil.
- After epoxy attachment is done by poured on the stator case and the stator palte palced on top of which was then in press using hydrolic press to get good results.
- After the coil stick perfectly to the case stator, can proceed with the installation of bearing in the existing housing on the stator case.
- Then insert shaft to bearing, and then locked by using bolt.
- After all the rotor and stator component was assembly, then the next step was installation Hall Effect sensor with aid from oscilloscope to see the phase commutation. And thats the end of assembly process.

C. Test Analysis

In the performance test of Axial Coreless Halbach BLDC Motor, obtained the following data.

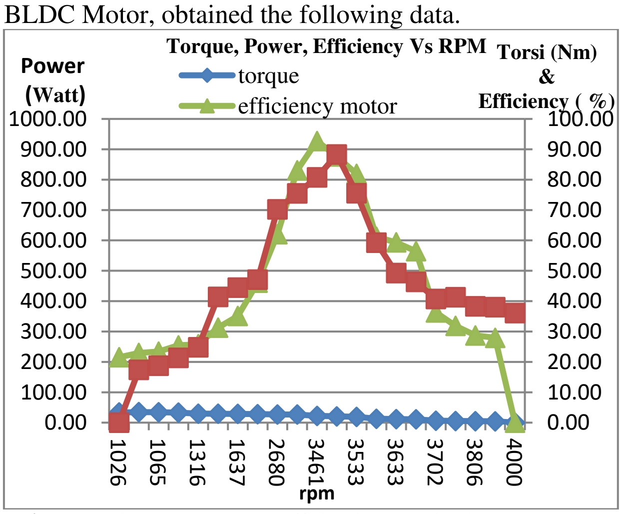

Figure 7. Chart Power, RPM, Effisiensi Vs Torsi (*Throttle* Konstan)

From figure 7 above it can be seen that by keeping a constan throttle openings showed the power output generated by Axial Coreless Halbach BLDC Motor reach peak until after the efficiency maximum at 3496 rpm. Then decrease with an increase in rpm of the motor. The motor efficiency is increased until it reaches the effective rpm and then decrease with the decrease in the output power of the motor. While the torque of Axial Coreless Halbach BLDC Motor values continued to decline in line with the increase of the rpm.

So it can be concluded that the Axial Coreless Halbach BLDC Motor highest efficiency is 92,72 % with a torque of 2,24 Nm and output power of the motor 907,34 Watt at 3451 rpm at 50% throttle position.

D. Power Density Calculation

Figure 8. Weighing Stator Set

Figure 9. Weighing Rotor Set

Where the formula for calculating power density is:

$$\text{Power Density} = {}^{\text{Peak Power Output}}/_{\text{Mass Motor}} \quad (4)$$

$$\text{Power Density} = {}^{882{,}75\ \text{W}}/_{1{,}583\ \text{kg}} \quad (5)$$

$$\text{Power Density} = 0{,}588\ {}^{\text{kW}}/_{\text{kg}} \quad (6)$$

From the calculation obtained power density of Axial Coreless Halbach BLDC Motor is 0,588 kW/kg.

IV. CONCLUSION

After the analysis of performance test, it was consluded as follows:

1. At throttle opening 50 % on the performance test result obtained output power 807,34 Watt, torque of 2,24 Nm, efficiency 92,72 % at 3451 rpm with power density 0,588 kW/kg. Performance test result is still not obtained the value when the motor is operating at 100 % throttle opening. This is because the use of non-standard dynamometer for testing, so the value of the performance test is still not reached the goal of the final project both efficiency and power density. Also the way of loading is precise, which should be done first load variation when the motor starts spinning until it reaches its maximum when the throttle opening round 100 %.
2. The result from the simulation of Axial Coreless Halbach BLDC Motor is rated torque 2,27 Nm, efficiency 95,07 % , output power 2061,28 Watt at rpm 8643,24.

REFERENCES

[1] Bouloukza Ibtissam, Mordjaoui Mourad, Medoued Ammar, Guerboussa, 2014, **Magnetic Field Analysis of Halbach Permanent Magnetic Synchronous Machine,** University of 20 August 1955-Skikda, Skikda, Algeria.

[2] Buøy, John Ola, 2013, **Development of High Efficiency Axial Flux Motor for Shell Eco-marathon,** Norwegian University of Science and Technology.

[3] Colton, Shan, 2010, **Design and Prototyping Methods for Brushless Motors and Motor Control**, Massachusetts Institute of Technology.

[4] Desanti, Ayuning Fitri, 2015, **Desain dan Rancang Bangun Axial Permanent Magnet Brushless Direct Current Motor 25 kW**, Institut Teknologi Sepuluh November.

[5] Gallo, Christopher A, 2008, **Halbach Magnetic Rotor Development,** Glenn Research Center, Cleveland, Ohio.

[6] Hooper, Ian, 2011, **Development Of In-Wheel Motor Systems For Formula SAE Electric Vehicles,** The University of Western Australia.

[7] Judhe, Andy, 2012, **Air Gap Elimination In Permanent Magnet Machines,** Worchester Polytechnic Institute.

[8] *Kidd, Matt D.; N. E. Loch; R. L. Reuben, 1998,* ***Bicycle Chain Efficiency****, Herriot-Watt University, Edinburgh UK.*

[9] Nurtriatono, Agus, 2015, **Rancang Bangun dan Uji performa Axial BLDC motor dengan out put 2000 watt,** Institut Teknolgi Sepuluh November.

[10] Rencana Sakti W, Hudha, 2014, **Rancang Bangun dan Uji Performa Axial Flux PM Brushless DC Motor**, Institut Teknologi Sepuluh November.

[11] Shen, Yang, 2012, **Novel Permanent Magnet Brushless Machines Having Segmented Halbach Array,** The University of Sheffield.

[12] Todd D. Batzel, Andrew M. Skraba, Ray D. Massi, **Design and Test of an Ironless Acial Flux Permanent Magnet Machine using Halbcah Array,** Penn State University, Altoona College.