Comparison and Analysis of Stator Plate Holder on Yokeless and Segmented Armature Machine

A F Desanti¹, D A Asfani¹, M N Yuniarto², Y UNugraha¹

¹ Department of Electrical Engineering, Center of Excellence for Automotive Control & System, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
² Department of Mechanical Engineering, Center of Excellence for Automotive Control & System, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Abstract. This paper deals with comparison and analysis of stator plate holder on Yokeless and segmented armature (YASA) machine. YASA topology consists of two rotors and one inner stator comprised of many independent segments. Core for stator uses Soft Magnetic Composite (SMC) to conduct the three-dimensional magnetic flux. All stator segments and concentrated winding are fixed with the aid of two annular plates. There are cavities on both plates which have the same shape as the shoe of the stator segment. Moreover, the deformation of the plates must be kept as low as possible and have very high yield strength because of stress from the bearing. A complex structure, high durability, and high electrical resistance are the challenges. Polyetheretherketone (PEEK) is usually used as the plates, however high price and manufacturing cost remain an issue. Some other materials have a possibility and approach to PEEK capability. In this paper, candidate materials will be developed as a specimen and tested on the BH - Curve meter. The BH-Curve data provide simulation on Finite Element Magnetic Method (FEMM). The advantages and disadvantages are discussed in this paper. The analysis result demonstrates that other materials possess a similar capability as PEEK related to YASA stator plate holder.

1. Introduction

Electric motor with YASA topology is one motor that have several advantages. By using the axial structure, YASA topology can be set in parallel. Therefore, the research carried out is simpler because it only needs to study one axial electric motor with a certain power. If a system requires more power, it can be done by stacking so that the power obtained will be two to three times greater. In addition, YASA topology has more effective cooling system because it uses direct cooling [1][2]. With YASA topology, the structure on the right and left side of the stator has the same distance so that it is utilized by using two rotors. Therefore, the electric motor with YASA topology has a higher torque weight ratio than other motors [3].

In general, YASA topology uses SMC core as a stator [4] [5]. The procedure of making cast SMC cores can simplify the structure of the YASA topology that is different from the electric motor stator.
in general. In addition, the SMC core has a small eddy current loss compared to silicon steel which creates the electric motor having higher efficiency [6][7],[10] Evaluations and validation of application SMC core in electric motor get more power, less losses and lighter electric motor. The stator structure in YASA topology cannot be differentiated from the stator plate holder which serves as the main holder of the SMC core as a stator. The characteristics required are strong, withstand high temperatures and uninfluential to the performance of the electric motor. Polyetheretherketone (PEEK) is a widely used material [8]. Nevertheless, high prices and complicated assembly processes become obstacles. This paper compares the materials utilized on the stator plate holder on YASA motor topology. This paper explains the basic construction of YASA motor topology includes design and simulation, the prototyping process with the results of testing, and the conclusion of the research that has been performed.

2. Methodology & Basic Construction

2.1. Mechanical Simulation

The study was conducted simulation and prototyping. In this paper, the focus is on the use of stator plate material so that the motor design has been determined. Furthermore, hysteresis graph testing and strength simulation for each type are performed. From this data, simulation is then performed to determine the motor's performance and validation through prototyping and testing. Sequences of activities are listed on flowchart below.

![Flowchart](image)

**Fig. 1. Research procedure**

2.2. Mechanical Simulation

YASA topology consists of two rotors and one inner stator comprised of many independent segments. Core for stator uses Soft Magnetic Composite (SMC) to convey the three-dimensional magnetic flux. All stator segments and concentrated winding are fixed with the aid of two annular plates. Those two annular plates in this paper are called a stator plate holder.
Table 1. Materials Parameters

| Number | Materials                  |
|--------|----------------------------|
| 1      | Steel 1020                 |
| 2      | Aluminium 7075             |
| 3      | Carbon fiber               |
| 4      | ABS plastic                |
| 5      | Polyetheretherketone (PEEK) |

The simulation uses five materials that usually apply as an electric motor construction. Details of material are presented in Table 1. All materials are simulated on mechanical and electrical. The restraint of the thickness of the stator plate is 1.75 mm. Those values are represented as the air gap between the stator and the rotor. The axial force is listed from 50 N to 450 N for the maximum. Paper [8] got the maximum axial force for 400 N, so the maximum value for 450 N is a proficient choice. The location and stable position are located on the inner diameter and outer diameter. This YASA machine is designed as portable and reusable all electric motor parts. Figure 2 shows the exploded of YASA machine.

![Fig. 2. Exploded electric motor with YASA topology](image1)

![Fig. 3. YASA motor](image2)

There are annular on each side that uses as bracket for the stator shell. These structures are more reliable and flexible for the research because the stator plate can put and change the other type of stator plate and plug again. On the inner side, there is a bearing holder that consists of two bearings and the maximum strength is located in that area.

![Fig. 4. Deformation simulation on stator plate holder](image3)
Figure 4 illustrates the effect of maximum force of PEEK as the stator plate. The graphic of stress, deformation and strain are listed along the Figure 2. PEEK got deformation below about 0.4 mm and ABS plastic on 0.6 mm. On the other side, steel, aluminium and carbon fiber got under 0.1 mm for deformation.

Fig. 5. Graphic of deformation on stator plate holder

Fig. 6. Graphic of stress on stator plate holder

Those deformation values are used to decide the material of stator plate based on the mechanical side. Moreover, deformation value also effects the air gap value and torque distribution. In general, all performances of the YASA electric motor are also determined on the stator plate capability.

2.3. Electrical Simulation
To detect the effect of using the stator plate holder material, the YASA motor simulation is used by replacing the material. The material list is presented in Table 1. The effect of the material along the stator plate holder can be seen in the core loss and torque produced. The simulation used is Ansys Maxwell. In the software, all material specifications, BH-Cuvre and permeability curve, are needed electrically. The specimens of each material are used for testing.
Figure 7. shows the testing process using a hysteresis graph machine. Specimen materials are given primary and secondary windings according to the ratio of the number of windings that have been defined. Afterwards, the magnetization and demagnetization process will start. One of the results of the testing of carbon fiber is shown in Figure. Even though the specimens of the material used are not commonly used for electric motors, such as silicon steel and SMC cores, testing must be performed because the data is used as input for material specifications in the simulation. Therefore, the curve formed is not in the ideal condition of BH Curve. Figure 8. shows the results of a Curve BH from carbon fiber material.

Based on the information that has been obtained from specimen testing, the data are used for simulation on Ansys Maxwell. Modeling is used to find out the effect of the stator plate material on magnetization and flux circulation. Stator uses stator modeling and winding of the permanent magnet. Between the stator and the permanent magnet, there is a stator plate. The stator plate is replaced based on the materials that have been examined. The image shows the stator section, stator plate, and permanent magnet.
In addition, the stator plate also affects stator losses. Figure 9. shows a loss on the stator due to the stator plate. It shows that using iron material results in the greatest losses. Whereas, using PEEK and carbon fiber results losses with almost the same value. [2] conducted research on the use of carbon fiber on PMSM motors with the effect of increasing performance. Then, the results of this test have the same positive direction as the results of this paper.

3. Prototyping and Testing

The prototype is built with a simple design and can support the process of loading and installation so that the costs incurred for research are not too large. Each SMC core wall uses enameled wire and coated insulation to preserve the reliability of its insulation value.

Figure 10 shows the SMC core with winding using enameled wire with a diameter of 1.8 millimeters and a total of 42 turns of the winding. Enameled wire used is a type of Polyvinyl formed enameled wire (PVF-0). This case is chosen because the cooling system on this motor uses direct cooling, which uses fluid circulated inside the stator area. Thus, fluid is required, although cooling also has high insulation resistance. The fluid commonly used is transformer oil. The maximum allowable temperature is 90 degrees Celsius so that class 0 is chosen.
Besides, the main casing and the right and left side retaining casing are made using aluminum through the CNC process so that they are precise and light weight. In the main casing, there are two tubings as a cooling channel. The side of the stator plate holder is clamped between the main casing and retaining the right and left sides. The screened SMC core is put in the wrong place, i.e. in one side of the plate holder. Furthermore, connection is carried out by the winding path according to the number of stator and rotor poles. Each joint is coated with heat and oil-resistant insulators so that when the motor is operated at high temperatures and transformer oil is applied, insulation damage will not occur in the joint.

After the connection process is complete, then the stator plate holder is mounted on one side of the main casing and enclosed with a retaining one side. Between the main casing with the stator plate holder and between the stator plate holder and the holder, there is a seal to hold the fluid so that there is no leakage outside or inside. It is also given an additional sealant for the best waterproof performance. This system has the advantage of being able to be assembled; so that, when problems occur in the winding or SMC core, it will be easier to do repairs and more economical. But of course, it needs to be considered in the seal and sealant. After all parts of the stator have been installed, the next two rotors are mounted on the right and left side. The installation uses jig and fixture to get precise and good results.
In the testing phase, YASA motor is coupled using a universal joint and installed with an eddy current dynamometer. Tests are carried out on each type of stator plate holder. The test results are shown in Figures 13 and 14. Figure 11 shows the losses produced while using various materials in the stator plate holder. The highest losses are produced by steel material with fluctuating value patterns. Therefore, steel material is the least recommended material due to its biggest losses. The highest power is generated while using PEEK material and the lowest is found while using the aluminum material.

In addition to testing the performance on the dynamometer, endurance testing is also carried out with a load for 120 minutes. This test is carried out to determine the ability of each material when applied to real conditions. The results of the endurance test are shown in Table 2.

| Materials | result        |
|-----------|---------------|
| Steel 1020| increasing temperature |
| Aluminium 7075 | normal |
| Carbon fiber | normal |
| ABS plastic | Breaking down |
| Polyetheretherketone (PEEK) | normal |

4. Conclusion
Motor with YASA topology has some advantages such as compact, large torque and high efficiency. However, the structure of the stator plate holder is made of expensive material that is difficult to produce. Therefore, in this paper, the material comparison can be used as an alternative. Alternative materials must meet stronger requirements and not significantly affect power. Based on the strength simulation carried out, carbon fiber has strength similar to steel and aluminum. Furthermore, based on the results of tests conducted, carbon fiber has losses that are not as big as steel and the power generated is not too far from PEEK. Thus, it can be concluded that carbon fiber can be used as an alternative to PEEK as a material for stator plate holders on motorcycles with YASA topology.
Analysis of the cooling and durability of the motor must be analyzed in the future.

5. References

[1] H. Vansompel, A. Rasekh, A. Hemeida, J. Vierendeels, P. Sergeant, and A. E. Modeling, “Coupled Electromagnetic and Thermal Analysis of an Axial Flux PM Machine,” *IEEE Trans. Magn.*, vol. 51, no. 11, pp. 1–4, 2015.

[2] H. Vansompel, A. Hemeida, and P. Sergeant, “Stator Heat Extraction System for Axial Flux Yokeless and Segmented Armature Machines,” 2017.

[3] B. Zhang, T. Seidler, R. Dierken, and M. Doppelbauer, “Development of a Yokeless and Segmented Armature Axial Flux Machine,” *IEEE Trans. Ind. Electron.*, vol. 63, no. 4, pp. 2062–2071, 2016.

[4] P. Viarouge and Y. Chalifour, “Soft Magnetic Composites,” vol. 40, no. 2, pp. 550–557, 2004.

[5] B. Zhang, *Soft Magnetic Composites in Novel Designs of Electrical Traction Machines*.

[6] P. Balažovič et al., “Development of a switched reluctance motor made of permendur,” *IEEE Trans. Ind. Appl.*, vol. 266, no. 1, pp. 2318–2322, 2018.

[7] L. Xu, Y. Xu, and J. Gong, “Analysis and Optimization of Cogging Torque in Yokeless and,” *IEEE Trans. Magn.*, vol. 54, no. 11, pp. 1–5, 2018.

[8] T. J. Woolmer and M. D. Mcculloch, “Analysis of the Yokeless and Segmented Armature machine,” vol. 2.

[9] K. Grace, S. Galioto, K. Bodla, and A. El-refaie, “Design and Testing of a Carbon-Fiber-Wrapped Synchronous Reluctance Traction Motor,” vol. 9994, no. c, 2018.

[10] B. Ma, L. Chen, Y. Wang, and J. Zhu, “Performance Evaluation of an Axial Flux Claw Pole,” vol. 28, no. 3, 2018.