Prototyping of Axial Flux Permanent Magnet Motors

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Abstract:

Axial flux motors have many advantages according to conventional motors. But, as it's known in general, the most important reason not to use axial flux motors as much as radial flux motors, is fabrication difficulties. In this paper, it's shown how to prototype an axial flux permanent magnet motor. Because of that, the difficulties are identified after prototyping job of the axial flux motor. Results that are caused by these difficulties are written. Physical advantages of axial flux motor type is established with this application. A single rotor, single stator axial flux permanent magnet brushless dc motor is produced to prove all of these.

Key words: Axial flux motor, prototyping motors, permanent magnet motor, bldc motor.

1. Introduction

The Axial flux motors, also named as the disc-type motor. It is an appealing alternative to the conventional motors due to its pancake form, compact fabrication and high power density. Axial flux motors are mostly convenient for electrical vehicles, fans, pumps, valve control, aviation systems, machine tools, robots and industrial equipments. This kind of motor's rotor has larger diameter than conventional motors' rotor. So that it gives high moment of inertia that can be driven as a flywheel.
The different pancake-type profile of the rotor and stator of axial flux motors makes it possible to generate varius and easily changeable designs. Axial flux motors can be designed as many assorted forms. Single air gap or multiple air gaps machines, with slotted, slotless or even fully ironless armature. In this paper its mentioned about single air gap and slotted axial flux motor's fabrication difficulties after manufacturing a prototype one of that.

One powerful side to use axial motor is the direct drive form. In some cases, rotors are perched in directly to power-transmission components because of optimising the number of parts, mass weight, volume, power transfer and mounting time. For example, electric vehicles with embeded wheel motors gives advantages as a simpler electromechanical drive system, higher efficiency and lower cost. Some types may also appear in pumps, escalators, elevators, lifting systems, fans and other types of machinery, introducing new levels of performance for these products. Axial flux motors used as a brushless dc motor in general. UVW or SinCos encoders, resolvers or other rotor position sensors are very significant parts of brushless dc motors.

Although there are many advantages to use axial flux motors, these kind of motors are not manufacturing commonly because of some disadvantages. Axial flux motors advantages and

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disadvantages by comparison of conventional motors may be summarized as follows[14-17]:
Advantages:

- Wider radius/length ratio
- Planar and adjustable air gap
- Higher power density
- Ideal design availability because of smaller volume and lower weight.
- Availability for higher frequency or lower speeds

Disadvantages:

- strong axial magnetic attraction force between the stator and rotor;
- fabrication difficulties
- difficulties in mounting the machine and keeping the stationary air gap
- manufacturing time is longer
- High costs in manufacturing because of longer time

However these advantages and disadvantages, many researcher investigate on different types of axial flux motors. Investigations for electric vehicle are more popular recently because axial flux motors have very good specifications to affect vehicle performance[1-6,13]. Some investigations are about developments on axial flux motors, as reducing thermal outputs[7], new design aspects[8-10], reduction of cogging torque[11] and modelling axial flux motors in different methods such as magnetic equivalent circuit[12].
In this paper, authors introduce prototyping of an axial flux permanent magnet motor and the complexities of fabrication on a single air gapped axial flux permanent magnet brushless dc motor.
From starting to the end, it's mentioned what can be encountered while prototyping an axial flux motor for all parts of it.

2. Prototyping

Miscellaneous processes are necessary to bring an axial flux motor to the prototyping status[13]. Firstly, all parameters must be determined for the motor that will manufacture. These parameters demonstrate physical dimensions of all motor parts. Axial flux motor's purpose to fabrication and the application's physical dimensions are significant parameters and have to be established at the starting of prototyping. If the motor that will prototype is an alternative motor, it's easy to determine many parameters. However, if a new motor will prototype that's never produced, all parameters have to be determined one by one and carefully because of no references.
Physical dimensions are significant for calculations like stators inner radius, outer radius, pole number, slot number, magnet dimensions if its magnetted motor, magnet's B-H characteristic, air gap length, length between tooths, and the etc. For instance, because of stator bottom steel thickness is influence the motor's performance, this parameter have to be determined accurately in order to reach desired power and efficiency. Besides, after determining essential parameters, magnetic circuit analysis have to be done with these parameters and geometric, magnetic, electrical parameters have to be arranged. As the result, power and efficieny can be obtained and the last physical dimensions will be known before passing through to the prototyping.
For these reasons, before passing through to prototype the axial flux motor, it's written a Matlab

program to determine all parameters. Owing to this program different results for different parameters could be seen. Also physical data of axial flux motor, which will prototype, could be established. After these analytical solutions, the fabrication work could be started with these obtained data. Some significant data provided in Table 1.

Table 1. Obtained key design parameters of the axial flux motor by Matlab program

Parameter	**Value**
Number of Poles	8
Number of Slots	24
Air Gap	1.0mm
Pole cross sectional area	0.0016m^2
Magnet cross sectional area	0.0013m^2
Number of phase	3
Slots per pole per phase	1
Electrical steel thickness	0.35mm
Diameter of copper	1.25mm
Motor mechanical speed in rpm (operating speed)	2200rpm
Total slot current	400A
Output power	2191W
Efficiency	0.96

3. Fabrication

Fabrication process is always the most difficult phase for the research and development experts. Because, mechanical operations need to be performed perfectly in order to realization of the designed motor. If it's an axial flux motor, fabrication difficulties increased one more time[14]. Many methods are applied in axial flux motor fabrication which aren't applied in radial flux motor fabrications. Besides, some features that are looked like advantage, may be return to disadvantages unless mechanical operations performed perfectly. Here is mentioned the encountered circumstances while fabricating a single air gapped axial flux permanent magnet brushless dc motor.

3.1. Stator

Manufacturing the stator which main magnetic field is producing inside and motor's most significant part, is very complicated. The windings which are placed of stators inside, creates the main power. The most difficult process of axial flux motor fabrication is production of the stator core. One stator core is making in single air gapped axial flux motors. Fabrication difficulties of stator core is summarized as follows and the stator steel core is disclosed at figure 1:

- While stator core steel can be attach piece by piece in radial flux motors, it have to be solid for axial flux motors. Because there is no symmetrical structure at axial dimension.
- Stator steel core plate becomes from a one piece of roll strip steel.
- Stator steel need to be wrapped tightly not to leave any gap. Desired dimensions for stator core is prepared from wrapping tightly one piece roll strip steel. Also the stator core is welded in 90 degrees in order to keep it tight. Welding stator steel must be carefully not to

havoc magnetic circuit.

- Because of stator steel plate is one piece, opening up slots are quite arduous. Drilling of multi-plated roll strip steel is both takes long time and requires mastery. Besides, slots must open up at the side which didn't welded.
- Although manufacturing in longer time, it has more availability about cost of prototype. Because no necessity for a pattern to cut stator steel plates.

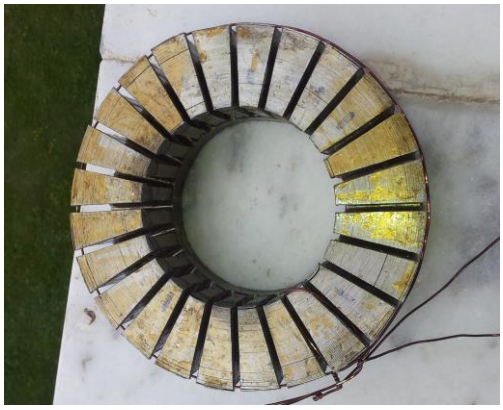

Figure 1. Stator steel core

3.2. Rotor

Owing to rotor is in the shape of disc, brings out some advantages to axial flux motor depending on the utilization objectives. There is one rotor in single air gapped axial flux motors. Some significant acquaintances are summarized below about fabrication axial flux motor's rotor:

- There are permanent magnets at the stator side of rotor. These magnet's B-H characteristic influences directly to the motor's output power. [14,18]
- Magnet cross sectional area is influence to magnet fraction parameter and it's used in air gap flux calculation. So bigger magnet cross sectional area higher air gap flux. [14,18]

3.3. Winding

Winding difficulty changes according to the type of axial flux motor. If it's slotless motor, winding is such simple. However, if it's slotted motor, winding is relatively harder. Also, winding can be done by varius geometries. It's hard to decide which one you will use. Some attained knowledge is shared below and an instantaneous of winding is disclosed at figure 2:

- in consequence of produced prototype motor is slotted, winding is made of one piece coil as in stator steel core. Distributed geometry is chosen for the winding. So coils distributed to the slots one piece for each three phase. That brought to return starting of winding if there is a mistake.
- One of the significant feature of the axial flux motor is the conductor packing factor is higher.

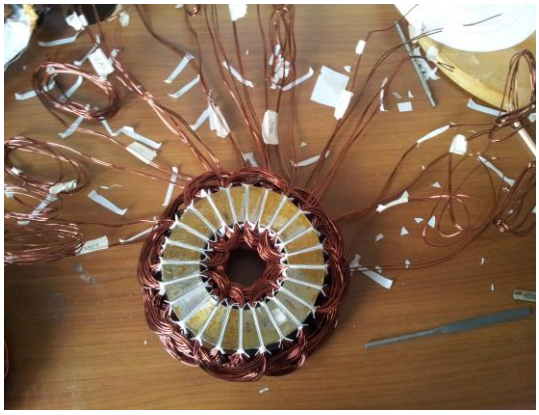

Figure 2. Distributed winding on stator steel core

3.4. Bearing

Bearing is one of the difficult work of prototyping axial flux motors. Some experiences are written below and mounted prototype motor disclosured at figure 3:

- Many of the papers about axial flux motor's advantages mention about adjustable air gap as an advantage. [15,16] That's accurate significantly, because air gap distance never change in radial flux motors without producing new one. On the other hand, bearing has key role here. Mistakes at millimetered margin can return to metallic works at producing prototype.
- Owing to the axial flux motor has strong permanent magnets, assembly and disassembly operations achieved arduousness. So, before stator and the rotor joined together, rotor and stator dimensions which will seat in the cover, needed to be calculated clearly.

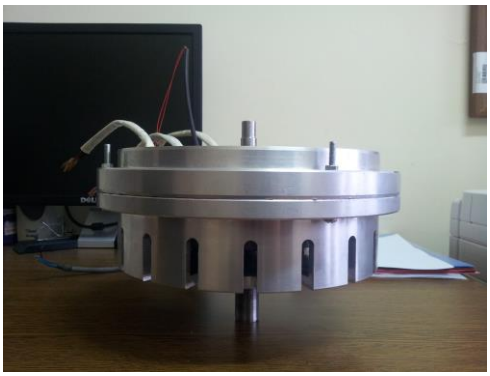

Figure 3. Mounted axial flux permanent magnet brushless dc motor prototype

Conclusions

Axial flux motors have many advantages by the side of radial flux motors (conventional motors). However, most significant handicap is the fabrication difficulties of axial flux motors. In this paper, fabrication difficulties mentioned based on prototyping of an axial flux permanent magnet

brushless dc motor. Although fabrication difficulties of axial flux motor, it always favoured when calculations and appropriate conditions are provided. Energy density and smaller volume cannot be ignored. This study ensured us, axial flux motors can produce by series production.

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