A Brief Review on the Axial Flux Disc Machines

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ABSTRACT: Due to its enticing features, hub motion lasting magnet or permanent magnet (PM) machines are being manufactured for some applications. There is a lot of information out there on the design of several types of hub motion PM machines. In this study, a diagram of hub motion, slot less, and opened distinct PM machines is presented. The Axial Flux PM machine (AFM) is explained in terms of its structure, areas of interest, and features. A few intriguing innovative hub motion machine topologies are also discussed from a variety of perspectives.

KEY WORDS: Soft iron, hard iron, permanent magnet, temporary magnet, Axial flux PM.

INTRODUCTION

The classic outspread motion PM machine's non-opened version has also been dissected in the writing. The presence of spaces and the type of poly phase winding are the two major differences between the opened and non-opened versions of the spiral motion PM machine. [1]. The stator construction is made out of a heap of covered steel and is not open. Because the accompanying poly phase windings are not placed into gaps, they are wrapped over the stator in a toroidal form and called air gap windings [2]. To increase power and improve conductor heat movement, epoxy pitch is put into the places in the center of the windings. Surface-mounted NdFeB magnets, as well as the rotor center and shaft, form the rotor structure. It's worth noting that with RFMs, only the windings facing the rotor PMs are used to generate force. End windings in this geography are the segments of the windings on the stators externally surface, as well as the parts on the two sides [3].

As a result, when the viewpoint proportion D/L (breadth over pivotal length) is small, this geography features lengthy end windings. All things considered, a small perspective percentage may result in a large copper loss. Because of the large air gap, the transition thickness is also reduced. Nonetheless, the construction of this machine has a substantial amount of freedom in that it readily transfers the warmth from the stator outline. As a result, machine electrical load may be very considerable [4].

AXIAL FLUX SURFACE MOUNTED PM MACHINES

The rotor structure determines how pivotal transition machines are classified. If the rotor structure is a squirrel cage, it is called a pivotal transition acceptance machine; if the rotor is formed by surface placed lasting magnets, it is called a pivotal transition surface mounted perpetual magnet machine [5]; if the rotor has an internal magnet structure, there is also a pivotal motion within the PM machine. The focus of this presentation will be pivotal transition surface mounted PM machines with different rotor configurations, but there will also be a brief overview of a few other types of AFMs and applications. The single rotor-single-stator construction, as shown in this article, is the most basic and simplest hub motion structure. The stator is made up of a ring-shaped twisting placed into an epoxy-like substance and an iron circle made from a basic tape wrapped iron core. The magnets are placed on a sturdy steel circle that forms the rotor.

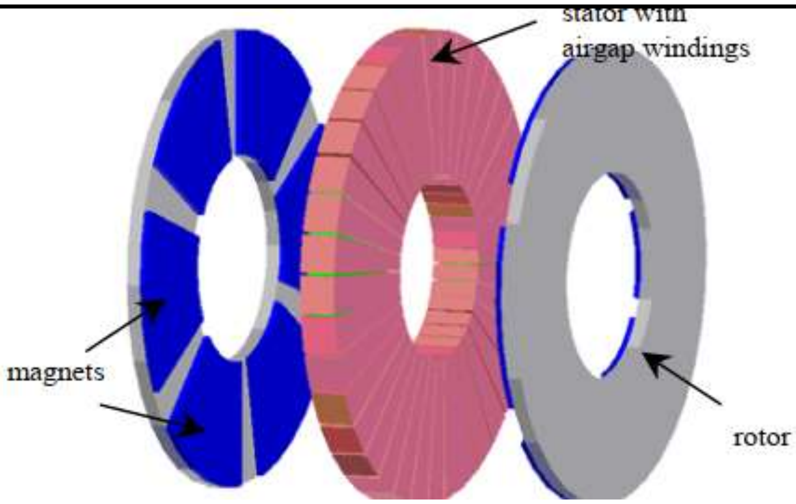

Fig 1: Axial flux TORUS type non-slotted surface mounted PM motor configuration (TORUS-NS) [6]**.**

The enormous pivotal power supplied to the stator by the rotor magnets is the main barrier to overcome in pivotal motion designs counting the single-stage construction. The structure might easily be contorted with this magnet power. If the stator teeth are removed, the pivotal power is reduced since it is applied to the iron rather than the copper windings. The TORUS-NS (non-opened TORUS machine) is a standard two-fold rotor-single-stator, hub motion, PM, slotless, disc type construction. This paper depicts a gilded version of the machine construction. A single stator is placed between two PM rotor circles in this machine. The machine's stator is identified by a tape twisted center with polyphaser AC air gap windings that are wrapped over the stator center in a sequential arrangement [7].

The interest in synchronous generators excited by Permanent Magnets (PM) is related to the global tendencies to support the power industry with the help of local power plants based on renewable energy sources such as water or wind energy, in which PM synchronous generators are often used. For these solutions, it is possible to develop a structure with a very large pole number and relatively small dimensions. The aim of the work is related to the search for design solutions for electromechanical energy converters with permanent magnets dedicated to small power plants. These include machines excited by PM with a radial magnetic field as well as disk machines with an axial flux permanent magnetic field [8].

The first Axial Flux Permanent Magnets (AFPM) machines appeared in the 1830s. In 1831 M. Faraday constructed a unipolar generator (the so-called Faraday disk), which was a machine with axial magnetization. This type of machine also appeared in N. Tesla’s patent, published in 1889. Earlier, in 1837, there was also a patent by T. Davenport [8], in which the first machine with axial magnetization was described. However, the wider development of axially magnetized machines started after 1983, when modern high-energy rare earth permanent magnets based on the combination of Neodymium, Iron and Boron appeared. Currently produced AFPM machines are characterized by a simple design and relatively small dimensions, especially in the rotor axis, as well high torque-to-weight ratio and efficiency. These benefits sometimes give AFPM machines advantages over conventional machines. AFPM machines are commonly used in various applications. In papers from the recent years, apart from the structural analyses of AFPM generators used for wind farms, there are more and more other possibilities of their use. One can mention here electric cars, traction drives and low-speed vehicles.

The stator construction of AFPM machines can be with or without armature slots, with or without armature core. Among the commonly used stator designs, there are two variants of the stator coil arrangement: non-overlapping and overlapping windings. The structure of the rotor is based on the selection of its type: internal or external permanent-magnet rotors, with surface-mounted or interior permanent-magnet and as single-stage or multistage. In recent years, a lot of research has been carried out to optimize the design and modelling of

AFPM machines. There are considerations for which analyses are carried out strictly on the basis of calculations of the magnetic field distribution with the use of numerical methods based on the finite-element method (FEM) and with the use of analytical models which also allow one to obtain quantitatively satisfactory results.

However, numerical modeling techniques do not easily allow a synthesized study for phenomena occurring in the machine, hence analytical models are very popular. For AFPM machines, there are some areas for which one can make some interesting considerations regarding complementation of the analytical models, similar to classic aspects of electrical machine modelling. Basically, analytical models are based on two approaches, analytical resolutions of the Maxwell's equations and the magneto motive force (MMF) by the presence product. The first analytical approach leads to very complex equations that are often difficult to accept by engineers. Mathematical models based on presence functions are more understandable for designers. Additionally, these models allow for analyzing the formation and reduction of cogging torques for iron core AFPM machines.

The aim of this article is the presentation of a universal analytical methodology that allows for comprehensive modelling of various designs of AFPM machines. This approach has not been widely published for this class of machines. This paper focuses in particular on a representative case of AFPM disc generators with a stationary stator with non-overlapping windings and two rotor discs. These solutions are well known; however, the aim of this work is to modify the structure and consequently, to correct the analytical mathematical models. The mentioned structure was chosen because of its simplicity, with the possibility of modifying the stator (coreless; with cores) and the arrangement of the permanent magnets (simple; skewed), in order to improve the generator characteristics and parameters, in particular to increase the obtained power and reduce the cogging torque. In this article, the four structures of AFPM generators ware considered, taking into account the higher harmonics of flux density distributions. An additional aspect of created models is their usability for operational purposes, e.g., cooperation with a six-pulse diode rectifier, which was also presented in this paper. The correctness of the result was obtained on the basis of the created mathematical models, and it was verified on the basis of laboratory tests and FEM calculations.

Axial-flux permanent-magnet (AFPM) machines have many unique features. For being permanent magnet, they usually are more efficient, as field excitation losses are eliminated, reducing rotor losses significantly. Machine efficiency is thus greatly improved, and higher power density achieved. Axial-flux construction has less core material, so, high torque-to-weight ratio. Also, AFPM machines have thin magnets, so are smaller than radial flux counterparts. AFPM machine size and shape are important features in applications where space is limited, so compatibility is crucial. The noise and vibration they produce are less than those of conventional machines. Their air gaps are planar and easily adjustable. Also, direction of main air-gap can be varied, so derivation of various discrete topologies is possible (. These benefits give AFPM machines advantages over conventional machines, in various applications. Published literatures on AFPM machines contain AFPM-related issues such as machine modeling, analysis and design. Comprehensive review of AFPM structures, modeling, simulation, analysis, design procedure and applications are attempted by this paper.

Subsequently, the study discusses various AFPM machine structures, advantages, and issues specific to each configuration, after which it reviews AFPM machines capable of flux weakening. Furthermore, it reviews points of sizing equation, modeling and simulation, and then it reviews diverse aspects of analysis, such as cogging torque, thermal and structural. More so, the study describes the design procedure of an AFPM machine as a multi-dimensional optimization problem to maximize the efficiency within constraints. Finally, the study suggests and presents potential applications, as well as future trends.

AXIAL-FLUX PERMANENT-MAGNET MACHINE CONSTRUCTION

AFPM machines were first introduced in late 70s and early 80s growing interest in AFPM machines in several applications due to their high torque-to-weight ratio and efficiency as an alternative to conventional radial-flux machines was significant in the last decade. Basically, each radial-flux-machine type has its corresponding axial-flux version. Practical categorizations are permanent-magnet DC commutator, permanent-magnet brushless DC, or synchronous AC. DC brushless and AC synchronous machines are equal in structure but differ in operation principle. EMF waveform generated by DC brushless is Trapezoidal. In AC synchronous it is sinusoidal. In construction, brushless AFPM can be single-sided or double-sided, with or without armature slots, with or without armature core, with internal or external permanent-magnet rotors, with surface-mounted or interior permanent-magnet, and as single-stage or multistage. Figure 2 shows various AFPM topologies and their winding configurations. Subsequently, the study focuses on AFPM machines of various rotor and stator configurations.

Figure 2: Various Topologies of AFPM Machines and their Working Configurations.

SINGLE-ROTOR SINGLE-STATOR AXIAL-FLUX PERMANENTMAGNET

This is basic and simplest-structure of AFPM machine; single rotor, single stator It is subject to unbalanced axial force between rotor and stator, so, unlike structures with balanced axial forces, it requires more-complex bearing arrangements and thicker rotor disk The magnetic force may twist the structure very easily. With slotless stator, axial force is less, as the force is exerted on iron, rather than on copper, windings.

DOUBLE-ROTOR SINGLE-STATOR AXIAL-FLUX PERMANENTMAGNET

This is TORUS, a double-rotor single-stator AFPM machine. Its phase coils wound around the slotted stator or the slotless stator. Slotless-stator TORUS-type AFPM machine was first introduced in the late 1980s Slotted and slotless differ in the existence of slots in one, and in the type of winding in each. For increased robustness and better heat dissipation of conductor, portions between air-gap windings in slotless are filled with epoxy resin. Leakage and mutual inductance in slotless air-gap windings are lower, and effects due to slots, that is, flux ripple, cogging torque, high-frequency rotor losses and stator teeth, are eliminated Windings in radial direction are used for torque production. In slotless, end windings are short, so, less copper losses, and better heat-dissipation of conductor (Aydin et al. 2001). Variations may be found in rotor magnet arrangement, which affects main flux path in rotor, in stator, and possibly in winding. In TORUS topology, main flux may flow axially through stator or circumferentially in stator yoke. Both structures show tangential

Lorentz forces affecting phase-A coils. The structures are identical except for stator-yoke thickness and winding arrangement. North-north (NN) structure has its phase winding wound around stator core, giving short end-windings (back-to back windings) in both the axial and the radial directions of the machine. Very short end windings reduce copper losses, but main flux has to flow. Circumferentially along the stator core, so a thick stator yoke is required, for summation of flux entering stator from both rotors, the summation in turn increasing iron losses and lengthens end-windings. Owing to its flux direction, the machine could be thought of as a combination of two independent halves. North-south (NS).

REVIEW OF LITERATURE

Among the many papers published in the field of axial flux permanent magnet disc machines, one titled "Axial Flux Permanent Magnet Disc Machines: A Review by Aydin, M., S. Huang*, T.A. Lipo" discusses how PM machines are progressively becoming more popular as the cost of high energy lasting magnets rises. These devices have a lot of intriguing features [9]. They are often more productive due to the fact that field excitation misfortunes are avoided, resulting in a reduction in critical rotor misfortune. As a result, engine output has skyrocketed, and greater force thickness has been achieved. In addition, PM engines have a low appealing thickness, resulting in low attractive measures. When it comes to hub motion PM machines, they offer a number of distinct advantages versus spiral transition machines (RFM). They're designed to offer a better strength-to-weight ratio while using less central material. They also feature air gaps that are flat and essentially bendable. The noise and vibration levels aren't quite what you'd expect from a machine. Similarly, the bearing of the basic air hole motion may be altered, allowing for the inference of many discrete geographies. These features provide AFMs distinct benefits over conventional RFMs in many applications. The purpose of this article is to analyze the AFM structures discussed in the literature as well as a few new and potential AFM structures. Hub motion surface magnet PM machines, which include slotless and open geometries with varying numbers of rotors and stators, are extensively examined. A general overview of AFMs, excluding surface magnet PM structures, is also provided. The method of measuring and planning is briefly summarized as well. Some motion-debilitating PM regions are also readily investigated from a machine setup point of view. As a result, machine electrical load may be very considerable [10].

DISCUSSION

This paper discusses about the non-opened variant of the famous outspread motion PM machine has also been examined in the literature. The existence of gaps and the kind of poly phase winding are the two main distinctions between the spiral motion PM machine's opened and non-opened variants. The stator is constructed of a mass of coated steel and is not exposed to the elements. Because the accompanying poly phase windings are not positioned in gaps, they are referred to as air gap windings because they are wrapped around the stator in a toroidal shape. Epoxy pitch is placed in the middle of the windings to enhance power and improve conductor heat movement. The rotor construction is made up of surface-mounted NdFeB magnets, as well as the rotor center and shaft. It's worth mentioning that only the windings facing the rotor PMs Produce force with RFMs. End windings are the segments of the windings on the exterior surface of the stators, as well as the portions on the two sides, in this geography.

As a consequence, this geography has long end windings when the perspective proportion D/L is minimal. Taking everything into account, a tiny perspective % may result in a significant copper loss. The transition thickness is also decreased due to the huge air gap. Nonetheless, the design of this machine allows for a lot of flexibility in terms of transferring heat from the stator outline. As a consequence, the electrical demand on the machine may be very high.

CONCLUSION

The motion of the hub this article examines a few new and promising AFM structures that were disclosed in the writing and a few new and promising PM machines that were announced in the writing. The AFM's machine architectures, standards, principle contrasts, highlights, and a few preferences are discussed. A selection of the enticing key transition PM new machine architectures are examined from many angles. Finally, an itemized and comprehensive reference section has been provided.

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