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AXIAL FLUX PMSM: STATE - OF - THE ART AND TRENDS OF DEVELOPMENT

Abstract. The paper presents a brief survey of the modern designs and performances of the axial flux PMSM, including the results of comparative analysis, the methods of parameters identification and issues of torque ripples. The evaluation of the axial flux PMSM performances and solutions of existing problems are highlighted.

1 INTRODUCTION

The history of the axial flux PMSM (APMSM) creation totals already about 50 years [1]. Those years were when the APMSM fundamentals of the theory and their design principles were founded and their main properties were revealed. The significant influence to development of these machines was rendered by achievements in power and signal electronics and electromagnetic material technology when the high-energy PM on the base of rare-earth metal neodymium - iron - boron alloy (NdFeB) was invented. In electrical machinery two new designs have appeared: the brushless DC machine (BDCM) and the PM synchronous AC machine (PMSM) of radial and axial flux types. The PMSM is capable of a higher speed and high performance applications [2]. The present stage of the APMSM development is characterized by design optimization, elimination of torque pulsations, implementation of new methods of sensorless and intelligent control. The aim of the article is the evaluation of the APMSM performances, discussion of problems and their solution.

2 DEVELOPMENT OF THE AXIAL FLUX PMSM DESIGNS AND COMPARATIVE ANALYSIS

As a whole an APMSM design is determined by both an amount of main components (number of stators and rotors) and their configurations (Fig.1). An elementary variant of single-side design has the large forces of stator and rotor attraction (Fig. 1a). Three- and more components constructions of the APMSM have no this defect and, besides, allow to grow up output power, increasing the number of stator and rotor modules (Fig. 1c) on the same shaft.

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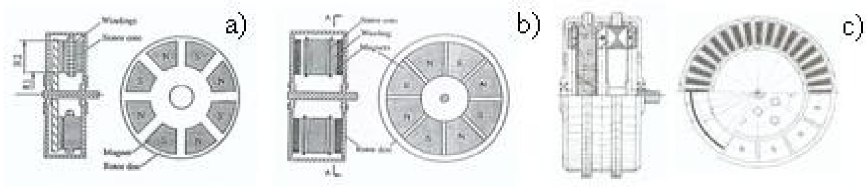

Fig.1. APMSM of single –side (a), double- side(b) and multi-disk type.

Well-known APMSM with internal and external magnets displacement on the rotor progresses now to the new principles of designing, including systems of Hallbach array, mosaic structures and variants with concentrators [4]. Using these solutions and innovations it is possible to obtain rotor magnetic field of required waveform with enlarged magnetic flux density and moreover to create an ironless stator APMSM [5]. The type of stator windings depends on the core profile (slot or slotless construction) but usually they are similar those in the RPMSM and have the distributed double layer configuration. In case of the APMSM with a double rotor and single stator it is preferable to use Gramma winding. A great deal of the RPMSM and APMSM configurations has caused cessity of their comparative evaluation.

One of the main technical characteristics, regarding to the comparison is executed, is power density, i.e. output power per unit of a mass or a volume. At present the following methods of comparative study are prevalent:

1. The numerical method based on computer simulation of each PMSM selected for comparison [6] that makes this method highly labor-consuming and small effective for wide practical application.

2. The analytical methods based on the application the sizing equations and power density expressions [7-9]. These methods are labor-intensive and their some factors have empirical character.

3. The machine geometry based methods [10], including an express method [11]. These methods are very simple and convinient for practical use.

Summarizing the results of comparisons by different methods, we may conclude, that at certain number of poles and with considering the criterion of similarity, the axial and radial PMSM have almost the similar performances on torque density, power losses and efficiency. But if the pole numbers of the APMSM is greater than 10-14 poles these machines are superior in terms of reduced permanent magnet mass and over-all volume.

3 METHODS OF THE PMSM PARAMETER IDENTIFICATION

The identification of the APMSM and DPMSM parameters by means of classical methods, based on two tests at open and short circuit outputs of the machine in generator mode of operation, does not ensure a required accuracy. The application of field theory methods and computer simulation is rather inconvenient because of large labor input [3], and also due to absence of exact data of the PMSM to be identified. The methods based on visual processing of voltage and current curves [3] are nether accurate and nor cost effective.

The method based on measurement of voltages and currents of an output volt-ampere performance of the PMSM in a loaded generator mode, is more effective, as it is largely free from the indicated above disadvantages. The method is based on the phasor diagram of the PMSM d-q model, with the help of which an analytical expression for two synchronous reactance x_{sd} and x_{sq} is geometrically derived as a function of load current and voltage. This equation is solved by the numerical method with help of voltage and current measurement data in two operation points of the generator.

4 PMSM TORQUE RIPPLES, CAUSES AND REMEDIAL STRATEGIES

A main drawback of the PMSMs is the torque ripples [2, 12] caused by four reasons: stator and rotor anisotropy, non sinusoidal distribution of the stator mmf, non sinusoidal distribution of the PM flux density and high harmonics in stator voltage and current waveforms due to application of power electronic switch mode converters for these machines operation. The torque can be separated into three components: cogging torque, PM torque and reluctance torque.

The cogging torque is a result of interaction between the PM field and the stator slotting. PM torque is caused by the interaction of the PM field with the stator mmf distribution and consists of two components: constant one caused by interaction of the fundamental harmonics of synchronous PM field and stator current mmf and an oscillating term resulted from the current and field high harmonics interaction. Reluctance torque is caused by the interaction between the stator mmf, stator slotting and rotor anisotropy and also consists of a constant and an oscillating terms.

For RPMSM a few remedial strategies are used now to reduce the torque ripple: skewing of the stator slots, introducing dummy slots in the stator, notches in teeth and dummy teeth of stator, skewing and shifting of the PMs, rearrangement of the PM pole-arc width, optimization of the PMs spatial angle displacement and others.

The detailed investigation [2,12] has discovered that the more preferable remedial strategy is based on the rotor structure design, without skewing. Concerning the torque ripples in the APMSM it is necessary to note that mentioned above remedial strategies do not always fit to these machines and so additional investigation should be carried out to choose an optimal method for ripple minimization.

5 CONCLUSIONS

1.At large variety the axial flux PMSM constructions the express method of comparison of these machine designs is very simple and convenient for practical use.

2.For requirement of maximum power density the APMSM is preferable in compare with RPMSM if the number of poles is more than 10-14.

3.For the axial and radial flux PMSM parameter identification the innovative method, based on measurements of the generator output voltages and currents is simple and effective.

4.There are a few sources of torque ripple components in the PMSM and the choice of optimal remedy for their reduction in APMSM depends on these machine peculiarities.

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