Optimalizace elektromagnetického návrhu PSMS stroje s axiálním tokem typu TORUS

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Optimization of electromagnetic design of TORUS Axial-Flux PMSM

Abstract – **The paper is dealing with the influence of choosing the optimal inner/outer diameter ratio on machines parameters. The Torus machines types are introduced with their structural options. Two NS Torus type designs for in-wheel application were made – in first case for machine with max. output torque, in second case for the best torque vs. mass ratio.**

Keywords – Electrical machines; Permanent magnets; Torus;

I. INTRODUCTION

With the development of rare-earth magnets and their decreasing prices, the permanent magnet synchronous machines (PMSM) became very popular, mainly for electrical vehicles applications. PMSM machines are well known for their higher efficiency since the excitation winding is absent; also the dimensions of these machines are in general smaller, plus the torque overload can be higher. For the in-wheel electrical vehicles (vehicles where the driving machine is located directly in the rim of the vehicle's wheel) the machines operating with axial flux comes to mind. The axial-flux machines have disc geometry which is more convenient for the in-wheel propulsion systems and their power density is much higher comparing to conventional radial-flux machines.

The axial-flux permanent magnet synchronous machines (AFPMSM) can be generally design as single rotor – single stator types, or as a machine with double stator or double rotor. In these cases we are speaking about TORUS type AFPMSM. The TORUS machines can be constructed with external stators and internal rotor or vice versa. More available options for TORUS designs are mentioned in [1]. While designing the AFPMSM, attention must be pay to choosing the ratio of inner and outer diameter has the crucial impact on all machine's parameters. This paper is discussing two electromagnetic designs of the external rotors internal stator TORUS machine with surface magnets, where the first design was focused on achieving the highest output torque and the second one was designed with the respect for torque vs. mass of the machine.

II. DESIGN OF TORUS MACHINE

A. Possibilities for TORUS AFPMSM design

As mentioned earlier, the axial flux machines have disc geometry, and unlike the radial flux machines they can be designed with variable air gap. The stator can be slotted or slotless with the winding fixed right on stator yoke. Using the slotless stator geometry brings advantages like elimination of cogging torque and also there are no teeth so the magnetic saturation is reduced. Even though the slotless stator is easier for assembly, this paper deals with a machine with slotted stator, since the in-wheel motor needs to have certain robustness.

Generally we can divide TORUS machines in two groups: the NN type and the NS type (see Fig. 1). This is related to the path of magnetic flux, which in the first case travels along the stator yoke and closes its path through the magnet with opposite polarity. The flux path for NS type goes in axial direction through the stator core and does not travel circumferentially along the stator yoke. Since the NS machine can be designed with much tighter stator yoke (the thickness depends mainly on mechanical endurance) we chose this geometry due to minimize the total axial length of the machine.

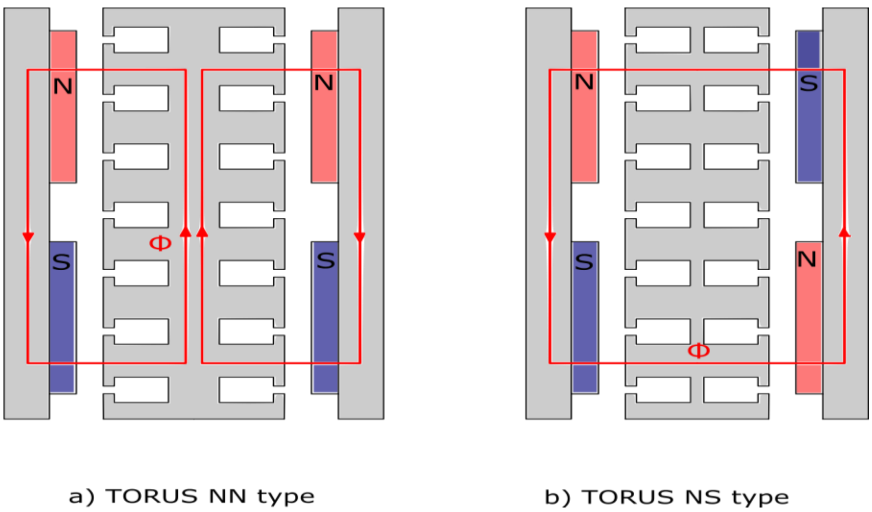

Figure I. **Flux directions for a) TORUS NN type and b) TORUS NS type**

B. Electromagnetic design of NS TORUS machine

The parameters which are the same for both machine designs are listed in Table I. Important parameter which has to be determined right at the beginning of the process is diameter ration k_D (1), it's a ratio of inner and outer of the machine. Since there is relation (2) between diameter ration k_D and output torque, it's necessary to realize that if we chose to maximize the output torque we should design the diameters with k_D around value around 0.58 (see Fig. 2). Obviously the smaller diameter ratio leads to higher total mass of the machine, so when there is mass limitation like in case of electrical vehicles application the compromise should be made. In [2] authors discuss the impact of the choice of k_D ratio and came with decision that optimal value should be in range 0.75 – 0.85.

$$k_D = \frac{D_{in}}{D_{out}} \tag{1}$$

$$T = 2\pi B_g A_{in} R_{out}^3 (k_D - k_D^3) \tag{2}$$

The first design which was focused on production of maximal torque was made for k_D = 0.6. In the second design we were trying to achieve already mentioned compromise between produced torque and mass of the machine, so the diameter ratio was 0.8.

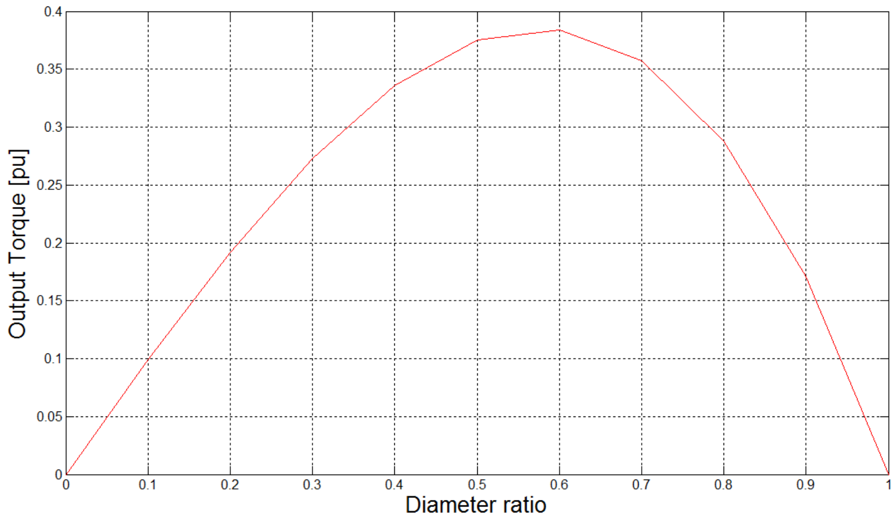

Figure II. **Relation between electromagnetic torque and diameter ratio k_D**

TABLE I. MACHINE'S PARAMETERS

Output Power [kW]	30
Rated Voltage [V]	100
Rated Current [A]	123
Rated speed [rpm]	600
Number of poles	10
Frequency [Hz]	50
Outer diameter [m]	0.450

During the analytical design of AFPMSM we work with the average diameter D_{avg}, because this value is different for both designs the stator and winding design differs too. In both cases, the stator winding is double layer fractional; the exact procedure of winding design is described in [3]. The basic parameters for each stator are in Table II.

TABLE II. PARAMETERS OF MACHINE'S STATOR

	Number of slots	Number of slots per pole and phase	Number of turns in series
k_D = 0.6	36	6.5	36
k_D = 0.8	42	7.5	70

Because the analytical design of every electrical machine contains lots of iterations and constant changes of some parameter in order to achieve desired, also with axial flux machines we have to some addition changes. The disadvantage of this type of machines is that unlike in radial flux machines, the output power is dependent on cube of the average diameter. This means that a slight change in value of inner diameter (for example because of increase of final linear current density) causes noticeable deviation in rated power. For example at Fig. 3 is shown influence of change of diameter ratio k_D on value of apparent power. In our case, for the machine with original $k_D = 0.6$ was this ratio, after finishing the winding design, decreased to value 0.54.

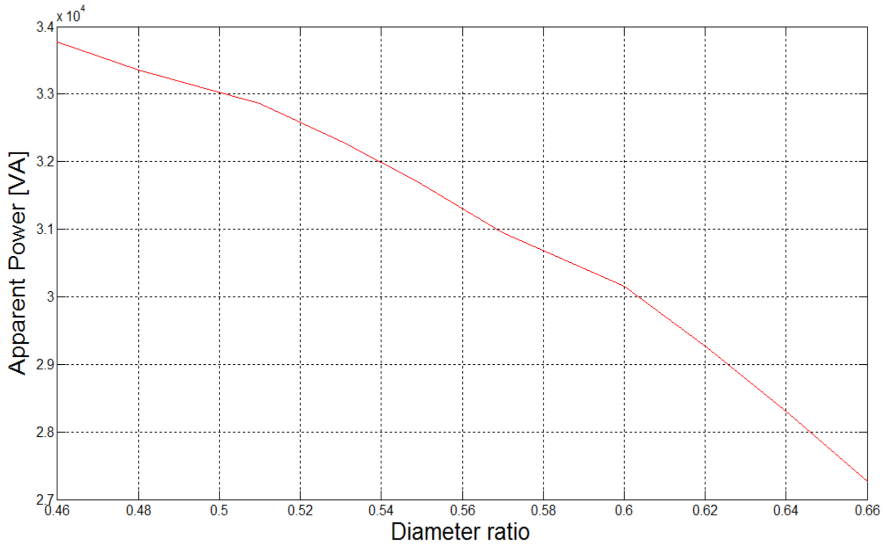

Figure III. **Influence of k_D on final apparent power**

III. Conclusions

The paper describes basic geometrical configuration for TORUS type AFPMSM which can be used for electrical vehicle with in-wheel propulsion system. Two design of TORUS NS type were made in order to determine the impact of choosing the diameter ratio on machines parameters.

Acknowledgements

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