Performance Comparison of Longitudinal Flux and Transverse Flux Permanent Magnet Machines for Turret Applications with Large Diameter

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Abstract —The aim of this paper is to provide performance comparisons between conventional longitudinal flux and transverse flux permanent-magnet machines using 3-dimensional finite element analysis considering both magnetic and mechanical fields. For a turret application with 2 meters in diameter size, not only electro-magnetic performance but also mechanical structural strength is important. Therefore, the comparison is focused on the torque density, machine efficiency, time constant, magnetic forces, and mechanical equivalent stresses occurred by the magnetic forces. For a specific turret application without an external cooling system, the obtained results provide an indication that which type of the machines is best suited regarding performance and size.

I. INTRODUCTION

Several papers have presented direct-drive machine designs, and the direct-drive machines from reference [1]-[3] are made for high torque and low torque ripple application, and they are based on surface mounted permanent-magnet (PM) machines. Most of these are about conventional longitudinal flux machines (LFMs). Some papers have insisted that transverse flux machines (TFMs) are good for direct-drive applications because of high torque density [3]-[5], but the TFMs have high torque ripple. And the TFMs with high torque are mostly consists of interior PM rotor or long axial length which are good components to increase torque even in LFMs. Moreover it is hard to find a paper regarding performance comparisons between LFM and TFM for direct drive applications under the fair and various conditions. One good example is in [3], but the conditions are focused on downhole applications which have limited outer diameter and relatively long axial length, and there is no consideration for mechanical construction.

In this paper, both longitudinal flux and transverse flux PM machines are investigated for turret applications where the machine inner and outer diameters are limited to 1 and 2 m respectively, and the axial length is also limited to tens mm by bearing thickness where are totally opposite configurations from downhole application shapes in [3]. The comparisons are focused on the torque density and machine efficiency for output performances, and resistance and inductance for precision controllability, and magnetic forces and mechanical equivalent stress for structural stability. All the comparisons are computed based on 3-dimensional finite element analysis (3-D FEA) for both magnetic and mechanical fields.

II. CONFIGURATIONS OF LFM AND TFM

According to the relative plane direction of the magnetic flux loop to the direction of motion, electric machines can be categorized into LFMs and TFMs [6]. In LFMs the loop of the useful flux lies in longitudinal or axial planes to the direction of motion. These machines are the conventional types, and they have generally distributed or concentrated windings. In TFMs the loops of the working flux lie in planes transverse to the direction of motion, and they have generally torus or ring shaped windings. Each of them has many construction variations, depending on specific applications. In turret applications, machine construction is chosen based upon the following considerations.

1) Cylindrical shape and radial directional air-gap: The turret system requires cylindrical pan-cake shaped machines. Since strong axial-directional exterior impacts are expected, radial directional air-gap is selected.

2) External-rotor machines: Normally, with the same dimension, external-rotor machines could provide higher torque density than internal-rotor machines because the former can have greater air-gap radius [3].

3) The shortest coils: Considering the limited machine volume, concentrated winding is considered for LFM and ring shaped winding is considered for TFM.

Fig. 1 shows the selected LFM and TFM configurations.

III. SPECIFICATIONS OF LFM AND TFM

To fairly perform comparisons between the two machines, some constraints have to be given, as listed in the following.

1) The inner and outer diameters and axial length are fixed because of the system volume limit.

2) The many pole number is good to increase torque and to reduce time constant in both LFM and TFM [3]. And in the case of using incremental encoder, the number of multiplier of 2 is good for number of pole to eliminate the accumulated position error. The number of PM segment in TFM was the same as that of LFM in the beginning. For the easy fabrication, PM was divided and shifted by a pole-pitch as shown in Fig.1 instead of stator core twisting as shown in [5]. Therefore the number of pole looks physically different, but the same number of pole is magnetically considered between the two machines.

3) Number of slot and phase: The variable pole and slot combinations can reduce torque ripple in LFM [2], but TFM has a limited combination because of separated core shaped and independent phase arrangement. Since torque

ripple can be reduced by several ways such as in [1] and [5], the variable pole and slot combinations are not considered in this paper. Phase is also fixed for the same standard control systems.

The assumed common constraints for the design are listed in Table I. The specific design have been done first for LFM under the condition that winding fill factor and current density are 70% and 4A/mm^2 respectively in addition to the common constraints in Table I because the turret system is totally enclosed. In the TFM design, the same rotor is used and only stator is redesigned. The axial length of stator tooth in TFM is the same as that of LFM to have the same outer volume, and the width of stator tooth is select to have the highest torque. The number of winding is selected for the same electro-motive force (EMF) at no load condition and the maximum speed.

IV. COMPARISON PROCEDURE

3-D FEA is used to compute the two motor performances and the non-linear magnetic characteristics of materials are considered. Fig. 2 shows the meshed models for magnetic field analysis. Considering periodic boundary condition, 1/128 model is used for the analysis model of LFM. In TFM only one phase among 1/128 model is modeled for magnetic field analysis due to the decoupling of magnetic flux paths and armature coils [7].

When the magnetic forces are calculated in the rotor model, the force calculation regions should be divided according to the number of PM, as well as the configuration of PM segments instead of calculating over entire rotor model. It is because local forces can cause mechanical stress although the vector sum is zero. In Fig. 3 the upper graphs shows the force calculation results for one segment part of the rotors. In TFM the z-directional force exists in local area but the overall force is zero. The lower figures in Fig. 3 shows the mechanical equivalent stress computation results in the rotors, and the all output performances mentioned in beginning of this paper are compared in Table II. The detail explanation about computation methods and comparison results will be presented in the extended paper.

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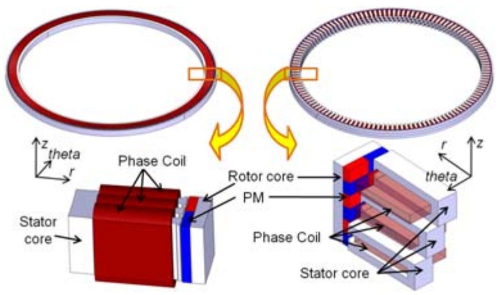
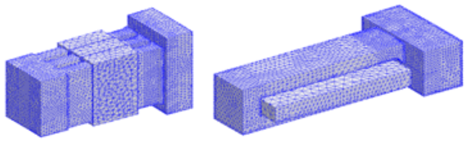


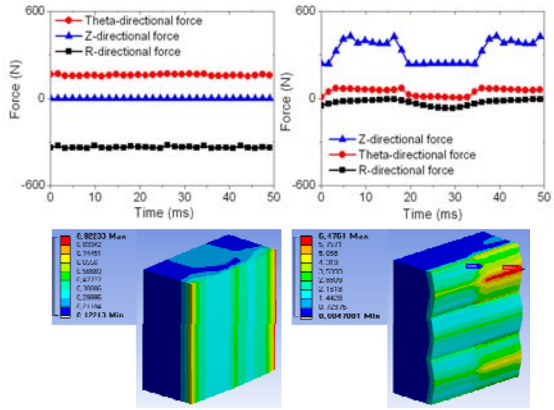
(a) LFM (b) TFM

Fig. 1. LFM and TFM for turret applications with large diameter



(a) LFM (b) TFM

Fig. 2. Meshed 3-D FEA model for magnetic field analysis



(a) LFM (b) TFM

Fig. 3. (upper) Force variations according to time in one PM and its back yoke of analysis models, and (lower) Equivalent stress in the rotor

TABLE I
COMMON CONSTRAINTS FOR THE DESIGN

Parameters	Values
Inner and outer diameters, and axial length	1.4 m, 1.6m, 70 mm
Maximum speed	14.3 rpm
Required torque (minimum)	5000 Nm
Number of pole, slot, and phase	256, 384, 3

TABLE II
PERFORMANCE COMPARISONS

Parameters	LFM	TFM	Unit
Total weight	203.9	164.7	kg
Electro-motive force	117.3	117.1	V(rms)
Time constant	15.7	79.0	ms
Torque density	29	30	Nm/kg
Efficiency	76.1	10.8	%
Equivalent Stress	0.9	6.5	MPa

V. REFERENCES

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