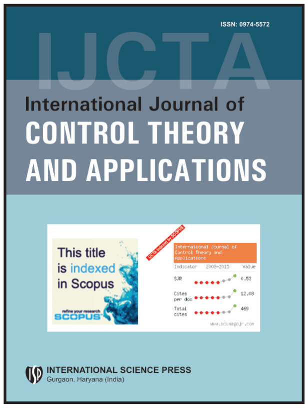

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Design and Analysis of Radial Flux Permanent Magnet Brushless DC Motor for Gearless Elevators

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Abstract: It is highly essential to realize direct drive systems in elevator to reduce size, vibration and maintenance. Application of induction motor with gear mechanism requires more space, frequent maintenance and results in to low efficiency. Permanent magnet motors are the best choice in direct drive elevator systems as they are inherently more efficient and compact. This paper presents design procedure of permanent magnet brush less DC (PMBLDC) motor used in elevator systems. Motor ratings are determined according to elevator application requirements. Three standard rating radial flux PMBLDC motors of 3.7 kW, 7.4 kW and 11.1 kW respectively are designed as per rating calculation and performance analysis is done. Finite element analysis (FEA) technique is used to validate design. Results obtained from FEA validate design outcomes.

Keywords: Permanent magnet brushless dc (PMBLDC) motor, Elevator, Finite element analysis (FEA), Direct drive.

1. INTRODUCTION

Drive train of elevator systems consists of a reduction gear for matching the low speed at which the pulley rotates with the high rotational speed of the conventional electric motors used as prime mover. Usage of such a mechanical arrangement has various demerits viz. relatively high acoustic noise and the need for regular maintenance due to lubrication oil. On account of these the direct drive mechanism is highly essential to obtain quieter and more reliable elevator systems. In addition to that, a machine room located on the top of building is used for installing the elevator drive system. Due to many architectural, commercial and structural constraints, a machine room actually cannot be used. These circumstances have motivated designer to realize compact, efficient and reliable room less elevator systems. Few solutions are (i) hydraulic elevators (ii) elevator systems with variable speed linear motor drive being used as counterweight and (iii) elevator drives with induction motor and reduction gear being installed under the car. Hydraulic elevator systems have limitations of trip distance and low speed, variable linear motor drive is costly and under car system suffers from high noise and maintenance difficulties.

To eliminate speed reduction gear and room the motor should be directly driven. High energy efficiency and compactness are key requirement of electric motor in direct drive elevator system. Permanent magnet motors are the best choice to obtain high efficiency and compactness compared to classical induction motors [1]. Permanent magnet motors offer many advantages like high efficiency, high power density, high torque to current ratio and large speed range. Design and geometric innovations have made possible the use of PMBLDC motors in various domestic and industrial applications. Advancement in the field of high energy permanent magnet materials and semiconductor converter have accelerated research in this domain. Design and performance enhancement of the permanent magnet motors has become research interest for many researchers. Permanent magnet motor based gearless elevators ensure enhanced performance at lifting up, stopping and moving. Gearless machines are low-speed, high-torque electric motors. As shown in Figure 1, a gearless driving machine is a direct-drive system in which there is no reduction gear between the motor and the drive sheave. The drive sheave is connected directly to the motor and brake. They are efficient and used for driving speeds greater than 2.5 m/s.

This paper presents comprehensive design procedure of radial flux permanent magnet brush less DC (RFPMBLDC) motor used in elevator systems. Firstly rating of motor is calculated according to three different load conditions of elevator systems. Design of three different motors is done. Computer aided design (CAD) programming is done for PMBLDC motor design and outcome of the CAD program is used as an input for FEA. Finite element analysis is carried out to analyse motor output and magnetic circuit. FEA output validates analytical design of the motor.

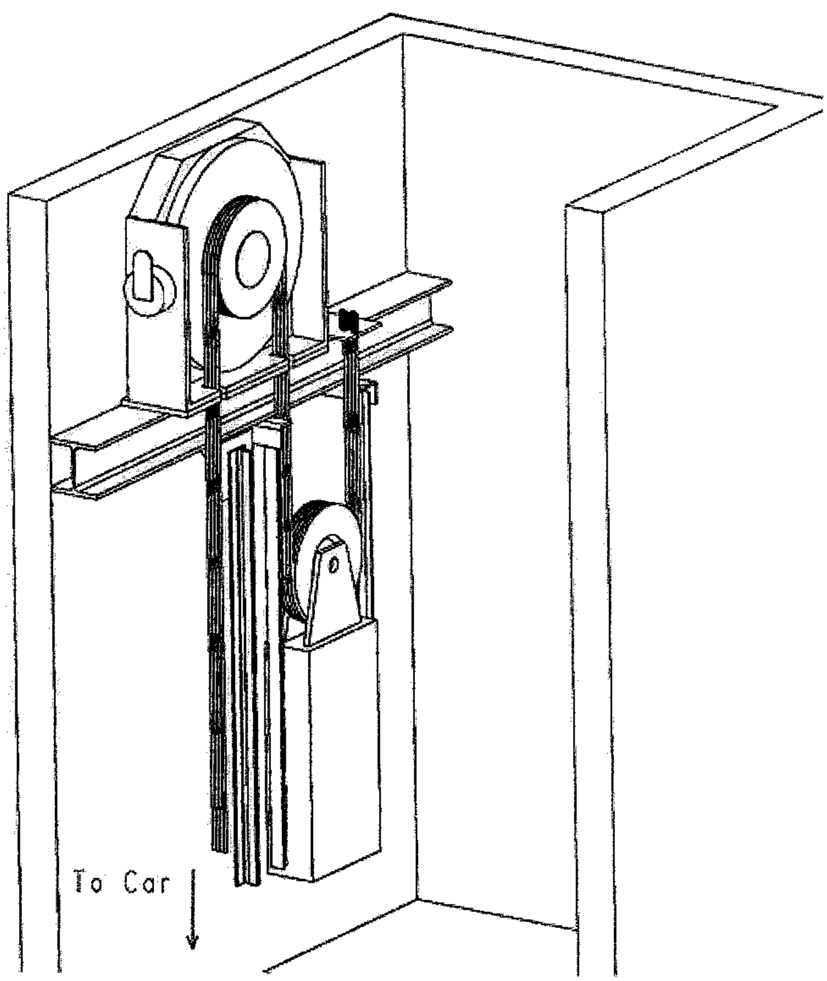

Figure 1: Gearless elevator Roping System

2. MOTOR RATING CALCULATION FOR ELEVATOR APPLICATIONS

In the design of radial flux PMBLDC motor, major requirements are torque and speed [2]. Based on dynamics of elevator system the motor ratings are calculated. The torque can be calculated as:

$$\tau_m = r_{\text{sheave}} \times g \times \frac{\text{M}}{\mu \times \eta} \tag{1}$$

where,

r_{sheave} : The radius of drive sheave

g : The force of gravity

M : Maximum carrying capacity

μ : The coefficient of suspension

η : Efficiency

$$\omega = \mu \times \frac{v}{r_{\text{sheave}}} \tag{2}$$

where,

ω : Speed

v : Car vertical velocity

$$n = \omega \times \left(\frac{60}{2 \times \pi}\right) \tag{3}$$

Motor rated power,

$$\text{P}_m = \tau_m \times \omega \tag{4}$$

3. DESIGN OF RFPMBLDC MOTOR FOR ELEVATOR APPLICATIONS

The design procedure of RFPMBLDC motor for elevator applications is shown by the flowchart in Figure 2. Motor rating is calculated from elevator dynamics system. Motor ratings are calculated for three different load considerations. Many design variables like specific magnetic loading, slot loading, torque to rotor volume constant, packing factor, current density and winding factor are to be assumed appropriately in order to obtain good design. Assumption of higher magnetic loading and slot loading reduce size of motor but increase losses. Usually average flux density is chosen between 0.4 to 0.9 T and slot loading is chosen between 150 to 400 A.

It is imperative to use high energy Neodymium iron boron (NdFeB) permanent magnet. Volume of permanent magnet depends on assumed magnetic loading [3]. Number of rotor poles are selected based on speed and frequency of flux reversal. Higher number of poles increase labour charges and frequency. Usually number of poles are selected between 4 to 8. Stator core is made up of thin laminations while rotor core is made up of solid mild steel. Shaft of motor is made up of stainless steel. The results are presented in following section regarding design of radial flux PMBLDC design model for three different load applications. Motor ratings are calculated for three different elevator loads of 340 kg, 680 kg and 1020 kg respectively. Table 1 shows ratings and design parameters of three motors.

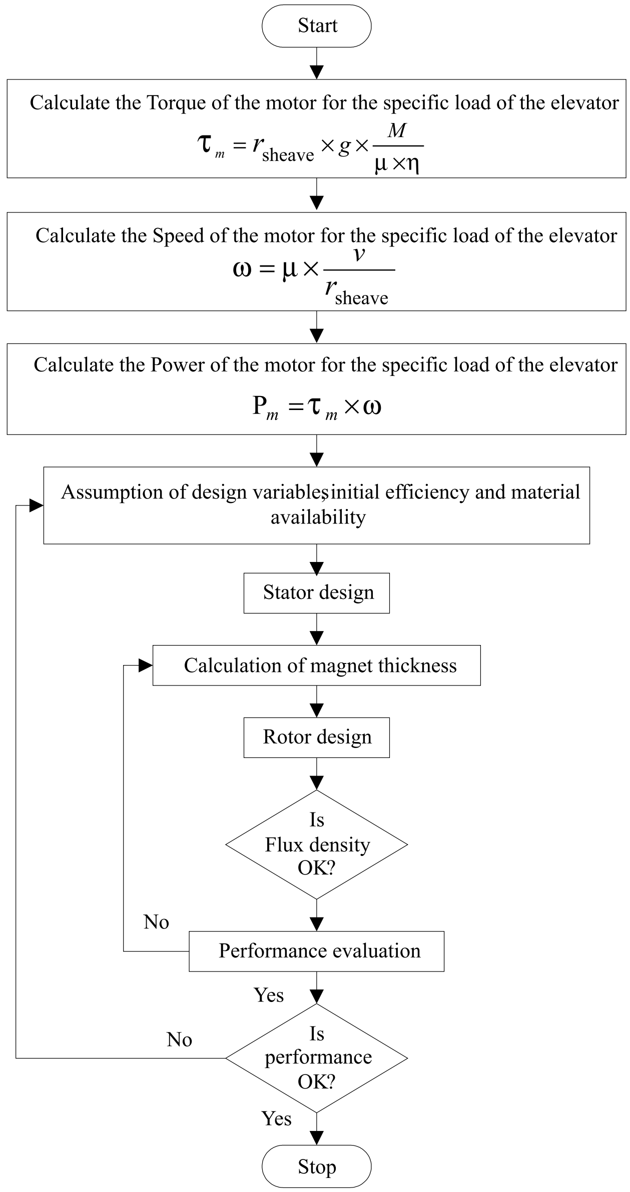

Figure 2: Flowchart of RFPMBLDC motor for elevator application

Table 1
Design Parameters of RFPMBLDC Motors

Parameter	*Unit*	*Value*		
		3.7 kW Motor	*7.4 kW motor*	*11.1 kW motor*
Torque	Nm	222.13	444..26	666.4
Efficiency	%	91	90	89
Stator outer diameter	mm	454	572	600
Stator bore diameter	mm	251	316	361
Axial length	mm	454	572	655
Magnet thickness	mm	2.7	2.7	5
No of slots	–	18	18	18
No of poles	–	4	4	4

Dimensions and performance parameters are calculated corresponding to assumed design variables. As per design output model is prepared and FEA is carried out to analyse performance parameters and flux density in various sections of motor. For 3.7 kW, Figure 3 shows model, Figure 4 shows flux density plot and Figure 5 shows torque profile. It is observed that flux densities established in various sections of motor is near to assumed flux densities.

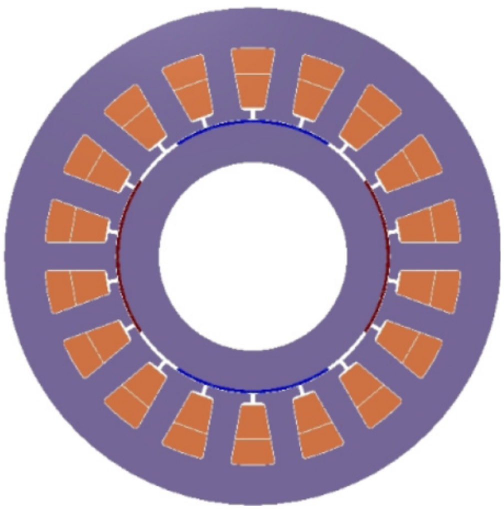

Figure 3: Model of 3.7 kW RFPMBLDC motor

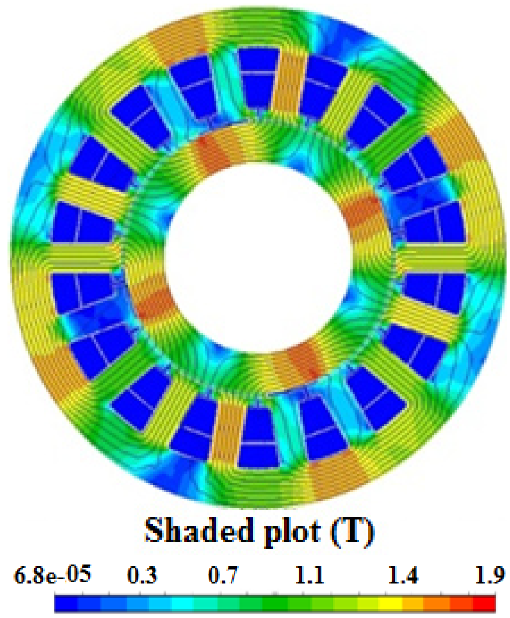

Figure 4: Flux density plot of 3.7 kW RFPMBLDC motor

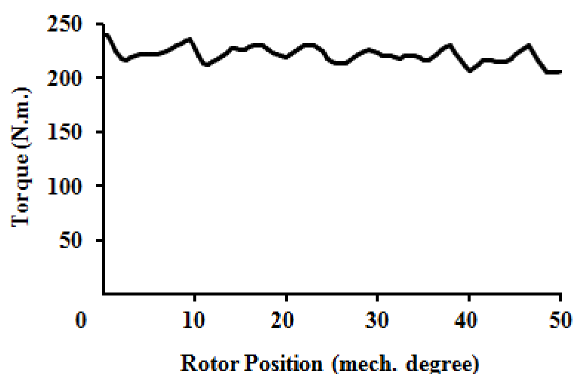

Figure 5: Torque profile of 3.7 kW RFPMBLDC motor

For 7.4 kW, Figure 6 shows model, Figure 7 shows flux density plot and Figure 8 shows torque profile. It is observed that flux densities established in various sections of motor is near to assumed flux densities.

For 11.1 kW, Figure 9 shows model, Figure 10 shows flux density plot and Figure 11 shows torque profile. It is observed that flux densities established in various sections of motor is near to assumed flux densities.

The comparison is done between CAD result and FEA results to check correctness of design. Table 2 shows comparison between CAD and FEA results. It is analysed that CAD results are fairly matching with FEA results. The minor difference is due to empirical formulas and nonlinear characteristic of magnetic materials.

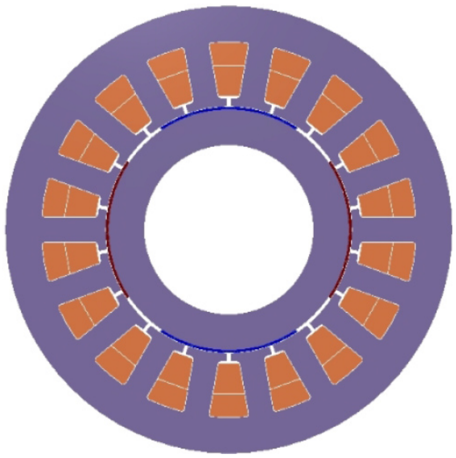

Figure 6: Model of 7.4 kW RFPMBLDC motor

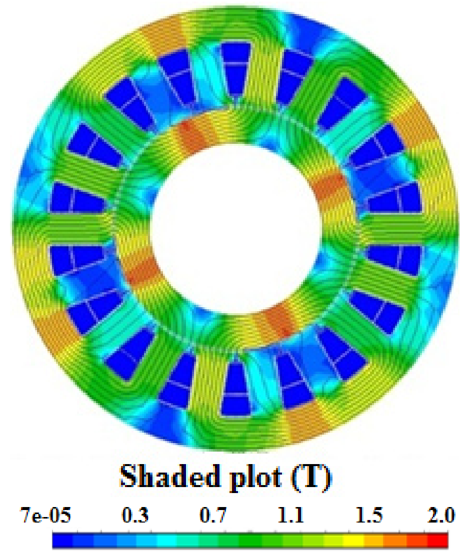

Figure 7: Flux density plot of 7.4 kW RFPMBLDC motor

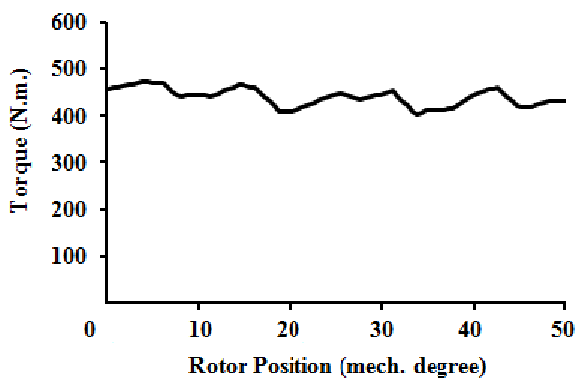

Figure 8: Torque profile of 7.4 kW RFPMBLDC motor

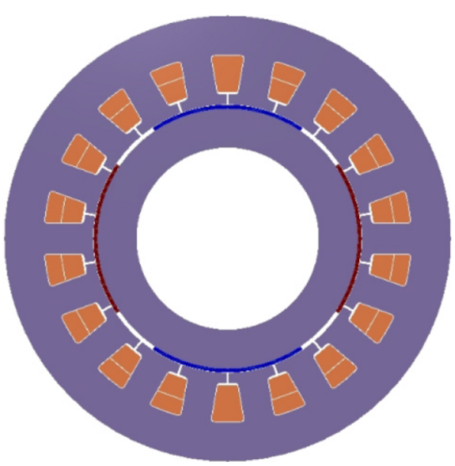

Figure 9: Model of 11.1 kW RFPMBLDC motor

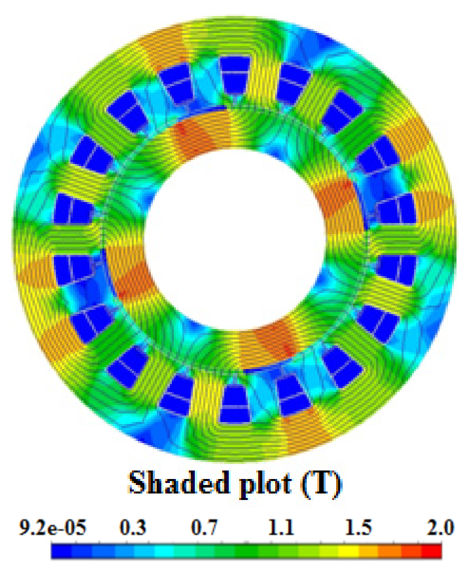

Figure 10: Flux density plot of 11.1 kW RFPMBLDC motor

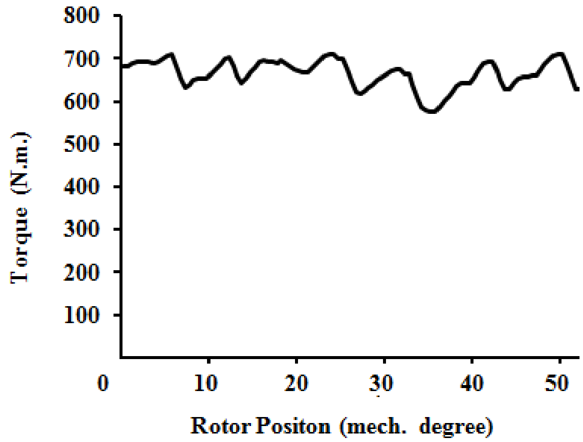

Figure 11: Torque profile of 11.1 kW RFPMBLDC motor

Table 2
Comparison Between CAD and FEA Results

Technique	*Parameter*	*Value*		
		3.7 kW motor	*7.4 kW motor*	*11.1 kW motor*
Computed by CAD	Torque (N.m.)	222.13	444.26	666.4
Computed by FEA		221	446	662
Computed by CAD	Stator Core Flux density (T)	1.5	1.5	1.5
Computed by FEA		1.46	1.48	1.49
Computed by CAD	Stator Teeth Flux density (T)	1.6	1.6	1.6
Computed by FEA		1.55	1.5	1.52
Computed by CAD	Rotor Core Flux density (T)	1.5	1.5	1.5
Computed by FEA		1.48	1.49	1.5

4. CONCLUSION

This paper presents application of permanent magnet motors in direct drive elevator applications. Motor ratings are calculated for three different load conditions and radial flux permanent magnet brushless dc motors are designed. Important design considerations for PM motors are also discussed. FEA is carried out based on CAD results. FEA results fairly validate and establish correctness of motor design.

REFERENCES

[1] D. C. Hanselman, *Brushless Permanent Magnet Motor Design*. NewYork: McGraw-Hill, 1994.

[2] Hicret Yetis, Hande Boztepeli, Yusuf Yasa, Erkan Mese, "Comparative design of direct drive PM synchronous motor in gearless elevator systems", *International conference on electric power and energy conversion systems*, October 2-4, 2013.

[3] J. R. Hendershot and T. J. E. Miller, *Design of Brushless Permanent Magnet Motors*. Oxford, U.K.: Oxford, 1994.