[5] Chong Won Lee: "Vibration analysis of rotors", Dordrecht; Boston: Klüwer Academic publishers, 1993.

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Assuming the following, we can calculate the requirements for thermal expansion.

Room temperature (T_{Room}) = 20°C

Normal operating temperature (T_{op}) ≈ 50°C

Maximum operating temperature (T_{max}) ≈ 150°C

Change in the shaft length due to change in temperature is given by:

$$\delta_T = \alpha.\Delta T.L$$

where δ_T = Change in the shaft length due to change in temperature (mm)

α = Coefficient of thermal expansion (/°C)

= 14×10^{-6} for steel

= 23×10^{-6} for aluminium

ΔT = Change in temperature (°C)

L = Original length (mm)

For Normal Operating Temperature					
Item	T_{Room}	T_{op}	ΔT	L	δ
Shaft	20°C	50°C	30°C	60.8mm	0.0426
Rotor	20°C	50°C	30°C	3.4mm	0.0039
				Total	**0.0465**
For Maximum Operating Temperature					
Item	T_{Room}	T_{max}	ΔT	L	δ
Shaft	20°C	150°C	130°C	60.8mm	0.1107
Rotor	20°C	150°C	130°C	3.4mm	0.0102
				Total	**0.1208**

A suitable manufacturing tolerance for shaft length would be say ± 0.05mm. Therefore, shaft length before the rotor disk would becomes:

Shaft length to rotor disk face = (60.8 – 0.0465 – 0.05) mm = 60.70mm.

This would ensure a constant air gap at normal operating temperature. The air gap on the other stator / rotor interface would still have to accommodate an axial growth of:

Maximum change in axial length (0.1208 – 0.0465) mm = 0.0743mm

Conclusion

The objective of this paper was the optimisation of the axial flux motor with respect to performance. This was confirmed through the utilisation of experimental and computational methods. The process identified that the most important parameter to rotor performance was the size, shape, and location of the permanent magnets.

Thorough analysis of the data presented indicates that the best magnet shape for the servomotor is the one used in Trial Rotor 2 as shown in Figure 3. This magnet shape as shown in Figure 6 produced the lowest cogging torque. Trial Rotor 1 produced the highest torque value for increasing the acceleration/deceleration, but gave the highest cogging torque values.

Reference

[1] S. Geetha, "Axial Flux Permanent Magnet Servomotor with Sixteen Poles", PhD Thesis, University of Wollongong, 1993.

[2] S.A. Moosavian, and A Basu, "A new Mechanical Design of a Servomotor, Mechatronics and Machine Vision". Edited by John Billingsley, University of Southern Queensland, Research Studies LTD., Baldock, Hertfordshire, England, *2000.

[3] A. H. Wijenayake, J. M. Baily, P. J. McCleer, "Design Optimization of an Axial Gap Permanent Magnet Brushless DC Motor for Electric Vehicle Applications", IEEE, 1995.

[4] M. Rosu, A. Arkkio, T. Jokinen, J. Mantere, J. Westerlund, "Demagnetization State of Permanent Magnets in Large Output Power Permanent Magnet Synchronous Motor", IEEE pp776-778, 1995.

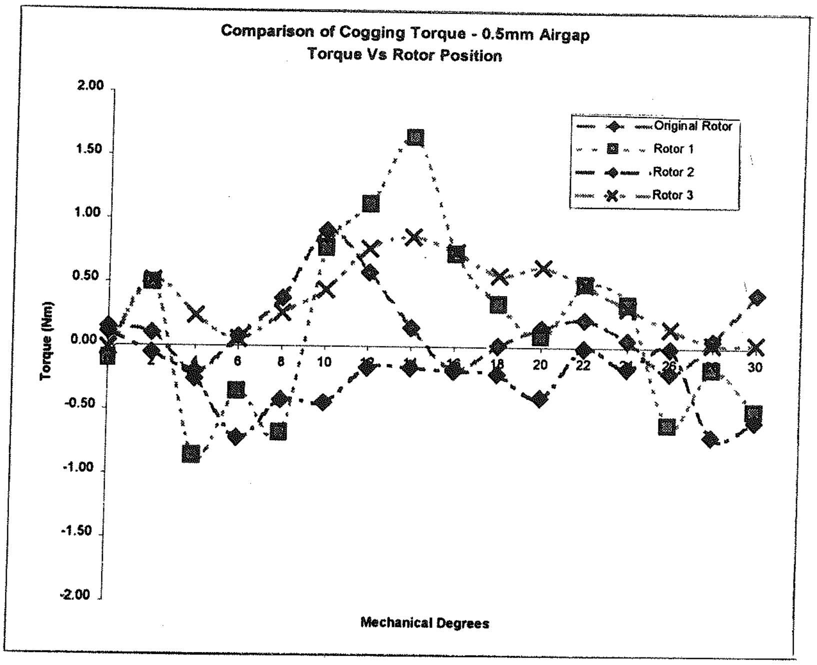
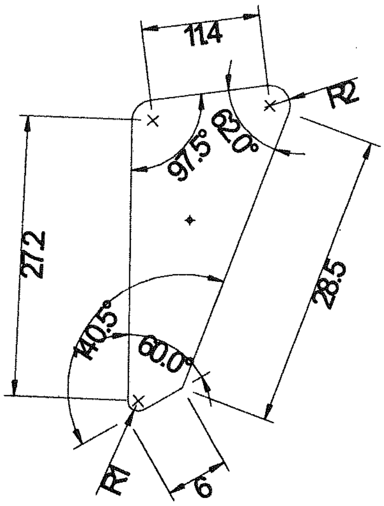


Figure (5) Cogging Torque for Trial and Original Rotors at 0.5mm Air Gap



Magnet Details
Material: Neodymium Iron Boron
Density: 7400 kg/m^3
Area: 305.6 mm^2
Mass: 7.69 grams

Figure (6) Selected Magnet Shape for Optimised Rotor.

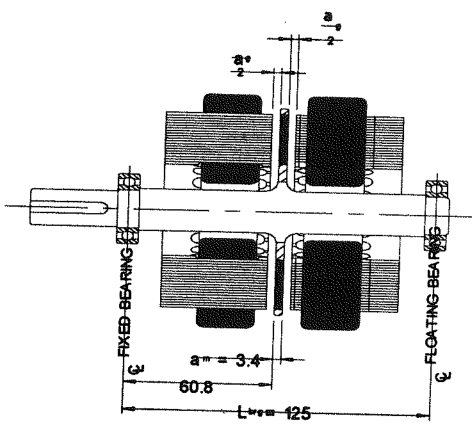


Figure (7) Relationship between Motor Bearings, Stators and Rotor.

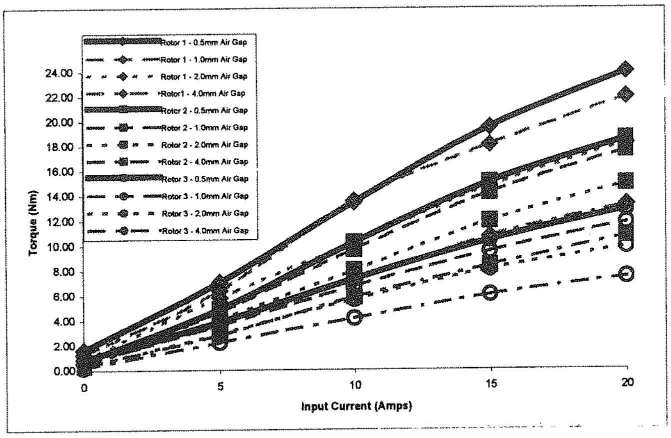


Figure (4) Input Current Verus Maximum Torque for Trial Rotors at a Variety of Air Gaps.

As can be seen in Figure 4 there is a significant difference in the torque production capabilities of the different shaped magnets. A smaller difference in torque production at different air gaps for the same magnet shape is also apparent. The maximum torque produced however, is not the only consideration in selecting the most appropriate magnet shape for servomotors.

Cogging torque is defined as the tendency of the rotor permanent magnets to "lock" onto the stator teeth. This cogging can be felt when turning the rotor of an electric motor by hand. Cogging torque is undesirable as it can produce vibration and noise. It is also an undesirable characteristic for servo systems that require smooth low speed operation. Figure 5 plots the cogging torque for each of the different rotor magnet shapes. The cogging torque was measured using the load cell at 0 input amps.

2- Selection of Magnet Shape

Thorough analysis of the data presented in Figure 4, it indicates that the best magnet shape for the servomotor is the one used in Trial Rotor 2. This magnet shape, shown below in Figure 6 produces the lowest figures for cogging torque with the second highest values for torque production. Trial Rotor 1 produces the highest torque figures, but also produces the highest cogging torque values by a significant margin.

3- Selection of Motor Air Gap

Data from the testing of Trial Rotor 2 indicates differing levels of sensitivities to the motor air gap. For an example a relatively small percentage difference (in the region of 5.5 percent) occurs in the doubling of the air gap from 0.5 mm to 1.0mm. A 19 percent difference occurs between the doubling of the air gap from 1.0mm to 2.0mm and a 41 percent difference between the doubling of the air gap between 2.0mm to 4.0mm. It is therefore apparent that the optimum motor air gap resides between 0.5mm and 1.0mm.

According to Ref [2] the air gap is also dependant upon the manufacturing tolerances required to commercially build the servomotor, allowances for thermal expansion, gyroscopic problem of the shaft and shaft deflection. Typical motor construction utilises a fixed bearing arrangement at the output shaft end, with a floating bearing at the other shaft end to accommodate any growth in shaft length due to thermal expansion. This type of bearing arrangement is also necessary for the axial flux servomotor under consideration. However, any variation in the rotor position, with respect to the stators, due to manufacturing tolerances or thermal expansion could have a significant influence on the performance of the motor. The relationship between the motor bearings, stators and rotor can be clearly seen below in Figure 7.

The test shaft was designed in accordance with AS1403 – Shaft Design Code for a maximum torque of 18 Nm. The shaft was also designed to fit the existing bearings and motor test frame. The grade of NdFeB provided was Grade N35H, with a maximum operating temperature of 80°C.

1-2-Trial Rotor Test Results

A series of tests were conducted to determine the torque production capability and characteristics of each trial rotor design.

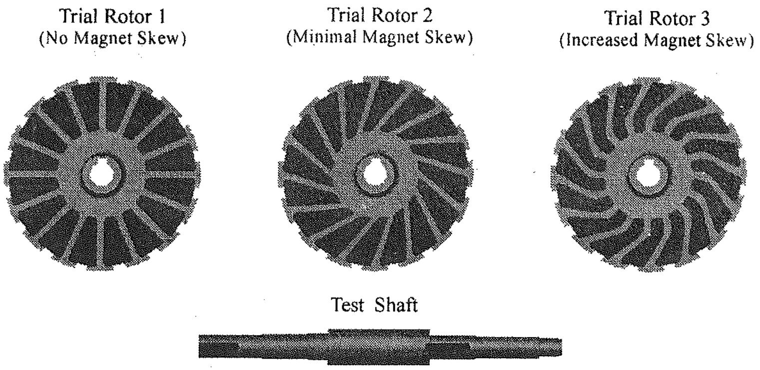
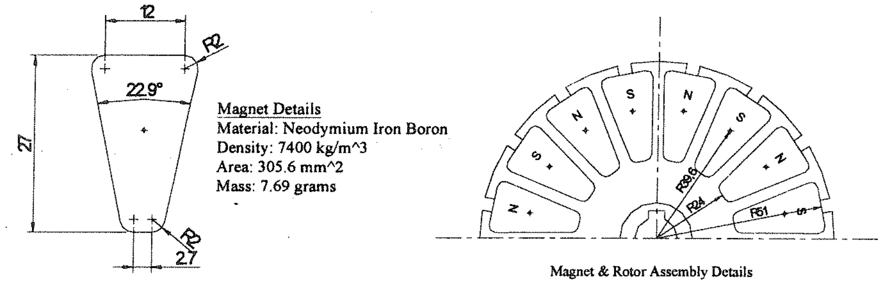
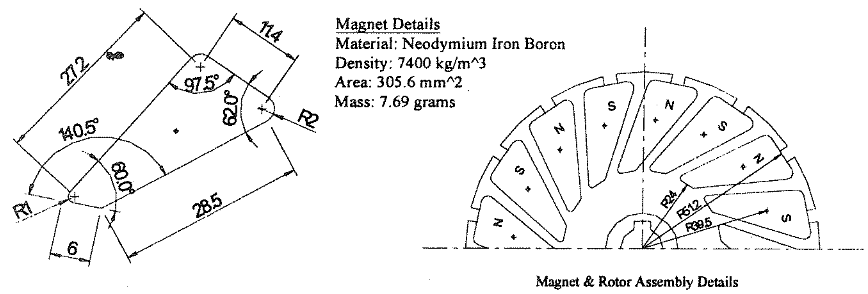


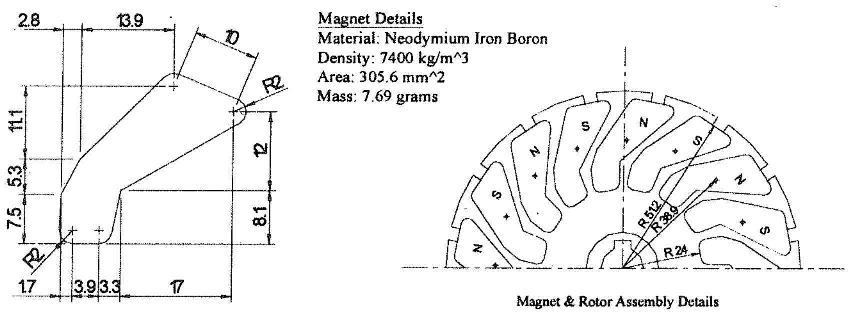
Figure (2) Trial Axial Flux Motor Rotors and Test Shaft.



a). No.1 Trial Rotor and Magnet Details

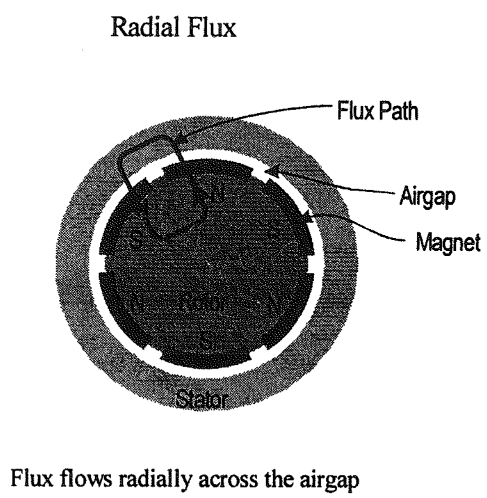


b). No.2 Trial Rotor and Magnet Details



c). No.3 Trial Rotor and Magnet Details

Figure (3) Trial Axial Flux Motor Rotors Details.



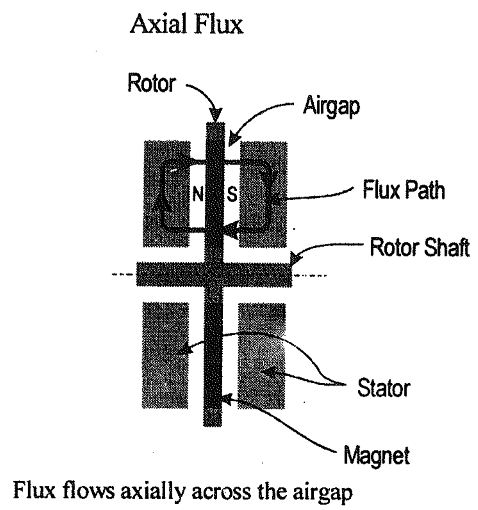


Figure (1) Comparison of radial and axial flux paths.

1- Motor Optimisation

Motor optimization is the methodical process of changing the machine parameters to attain the desired outcome. This desired outcome may be the most powerful/smallest/lightest/fastest/cheapest/or efficient motor for the application under consideration. Due to the large number of variables involved in motor design it is necessary to fix a certain number of these parameters such that the remaining parameters can be modified to meet the objectives of the optimisation process. It is normally the desired power output or torque at a certain speed that are the fixed variables.

Wijenayake, et. al have documented an optimisation process for an axial gap permanent magnet motor [3]. The process described is a multi objective optimisation procedure and assumes that the rated output power, rated speed and rated input voltage are given. Input data is grouped into seven categories:

1- Ratings and Configuration
2- Stator Data
3- Stator Winding Data
4- Slot Geometry Data
5-Magnet and Air Gap Data
6-Other Data (includes shaft diameter, rotor thickness, materials densities, etc)

Rosu, et. al documented that a high pole number is advantageous when optimising the motor construction in relation to size and mass [4]. Higher pole numbers result in shorter pole pitches and since the flux is proportional to pole pitch, smaller stator and rotor thicknesses can be utilised. This in turn results in a thinner permanent magnet thereby reducing rotor inertias, centrifugal forces and material costs [5-6].

1-1-Trial Rotor and Permanent Magnet Details

The trial rotor assembly was composed of the following components:

A common steel shaft with keyways to retain aluminium hub and lever arm for the locked rotor tests.

Three spoked aluminium trial rotors that were interchangeable. The aluminium rotors were fitted to the common steel shaft with a key and a slight interference fit.

Three sets of sixteen NdFeB magnets displaying varying amounts of skew. All magnets possessed the same area and thickness to provide a valid basis for comparison.

The interchangeable rotors were manufactured from Aluminium alloy 2011. This grade of aluminium was readily available in bar form and had good machinability characteristics. It was also the same material that the original rotor hub and circumferential ring was manufactured from. The construction of the test rotors was however, significantly different. It can be seen from the Table 5 as given in Ref. [2] that the circumferential ring comprised 28 percent of the total moment of inertia. It was therefore decided to minimise this circumferential ring (Figure 3).

A New Mechanical Design Optimization of Servomotor with Respect to Performance

A. Basu

S. A. Moosavian

Department of Mechanical Engineering,
University of Wollongong, Wollongong

M. H. Korayem

Department of Mechanical Engineering,
Iran University of Science and Technology

Abstract

A servo system moves a mass from one position to another as quickly as possible. A servomotor requires very high short term torque and should be able to accelerate and decelerate very quickly. In other words, a servomotor should be able to produce high torque and its inertia must be low. This paper concentrates on the mechanical design optimisation of the motor shaft and rotor assembly, given the existing physical constraints of the prototype motor. The existing physical constraints include the stator and rotor dimensions. To reduce the cogging torque, the different magnet shape and skew were manufactured and tested. Optimum shaft and rotor configuration were developed using theoretical calculations and FEA techniques. Using the above design the ratio of torque to the moment of inertia of the rotor goes to its minimum amount. As a result, the acceleration and deceleration of the system is improved.

Key words

cogging, inertia, acceleration

Introduction

Electric motors are devices that convert electrical energy into mechanical energy, they are comprised of two components (a rotor and stator), and operate through the interaction of a magnetic flux with an electric current. Electric motors can be broadly classified as either direct current (DC) or alternating current (AC), and then further classified according to their construction and modes of operation [1].

Permanent magnet motors can take the form of a conventional DC motor in which the stator winding is replaced by permanent magnets or a synchronous motor in which the rotor winding has been replaced by permanent magnets. The advantage of permanent magnet motors is that those do not require external excitation and it's associated losses to generate a magnetic field. In the case of AC motors, they also do not require commutators, making the machine smaller and potentially cheaper to produce. However, permanent magnet motors are subjected to the limitations of the permanent magnets themselves. This includes limits on the magnitude of air-gap flux densities generated and the possibility of demagnetisation of the magnets due to excessive currents in the stator windings or overheating of the magnets [2].

Motors can also be defined by the direction in which the magnetic flux crosses the air gap between the stator and the rotor. Conventional motors are considered to be "radial" flux machines as the flux flows radially across the air gap, while axial flux motors have comparatively thin disc rotors and a flat plane air gap, in which the flux crosses in the axial direction (Figure 1).