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Performance Analysis and Parametric Study of a Co-axial Magnetic Gear

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***Abstract*— Use of a magnetic gear in power transmission has many advantages over a conventional mechanical gearbox. Not only can magnetic gears operate at very high speed, they do so without a need for lubrication, cooling and also while generating a very minimal noise and vibration whilst being more reliable. The paper describes the basic design of a co-axial magnetic gear which employs Nd-Fe-B 35 rare earth magnets, followed by simulation study and multiple parametric studies.**

***Index Terms*— Co-Axial Magnetic Gear, Gearbox, Parametric Study, Power Transmission.**

INTRODUCTION

The basic function of a gear is to convert mechanical power from one operating speed and torque to another. Power input with high torque and low speed are required for many applications such as conveyor belts. Reliable power sources such as electrical machines and IC engines produce output in the form of high speed and low torque. Direct coupling of input and output is infeasible because of its large volume and very high cost, hence the source and application cannot be coupled directly. The solution to this problem is to use a transmission device. Gears can be used for such purposes. Mechanical Gears have been used in one or the other form since the age of Archimedes, requirement of cooling and lubrication along with noise and vibration sets forth this option as a less reliable one when compared to a Magnetic gear. Even though mechanical gears are able to produce high torque densities, Magnetic gears are capable of achieving high efficiency and are more reliable, in fact it has been shown that magnetic gears are capable of achieving torque density upwards 100 kN/m^3 [1]. Careful considerations are to be made regarding the magnetic gear design. This paper describes the basic design of a co-axial magnetic gear and its performances based on simulation studies. Due to their high reliability, high efficiency, no need of lubrication or cooling and the absence of vibrations portray magnetic gears a viable alternative to mechanical gears in applications involving high torque transmission such as wind power generation, ship propulsion etc. A parametric study is then carried out to assess the best possible combination of various parameters to achieve optimal output during the later studies.

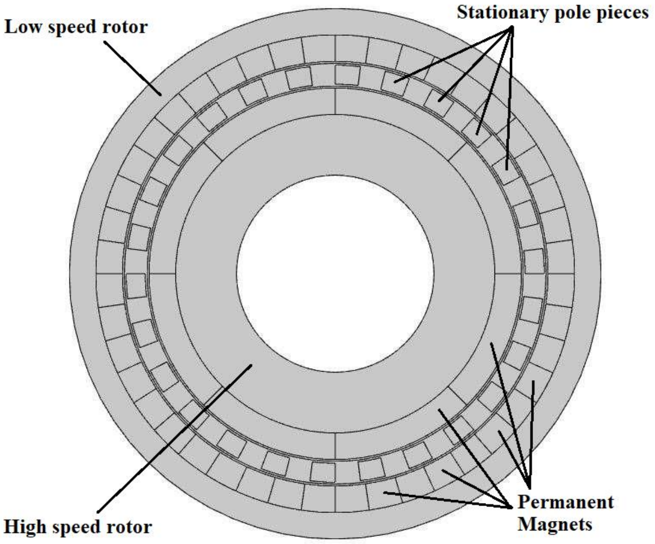

Fig. 1. Schematic of co-axial magnetic gear.

I. BASIC DESIGN AND PERFORMANCE

Fig. 1 shows the basic topology of the co-axial magnetic gear used for simulation study. Number of poles on the low speed rotor, high speed rotor and the number of stationary pole pieces can be determined from:

$$p_{g,m} = gp + mn_s \qquad (1)$$
$$m = 0, \pm1, \pm2, \pm3, \ldots, \pm\infty$$
$$g = 1, 3, 5, 7, \ldots, \infty$$

where p is the pairs of poles on permanent magnet rotors, and n_s is the number of stationary pole pieces. As p = 4 and n_s = 26, 22 or 30 is the best suited number of pole pairs on the low speed rotor, 22 is the chosen number of low speed magnetic pole pairs chosen for simulation study.

$$G_r = \frac{gp}{|gp + mn_s|} \qquad (2)$$

Assuming g = 1 and m = -1, we arrive at a gear ratio of $\frac{1}{5.5}$, also it has been shown that the maximum torque transfer occurs with this combination of number of permanent magnetic pole pairs and the number of stationary poles [2].

Table I
Parameters of co-axial magnetic gear

Parameter	
Number of pole pairs on high speed rotor	$p_h = 4$
Number of pole pairs on low speed rotor	$p_l = 22$
Number of stationary pole pieces	$n_s = 26$
Outermost Diameter	140mm
Airgap thickness	1 mm
Remanence magnetic field of magnets	$B_r = 1.25$ T
Relative permeability	$\mu_r = 1.05$

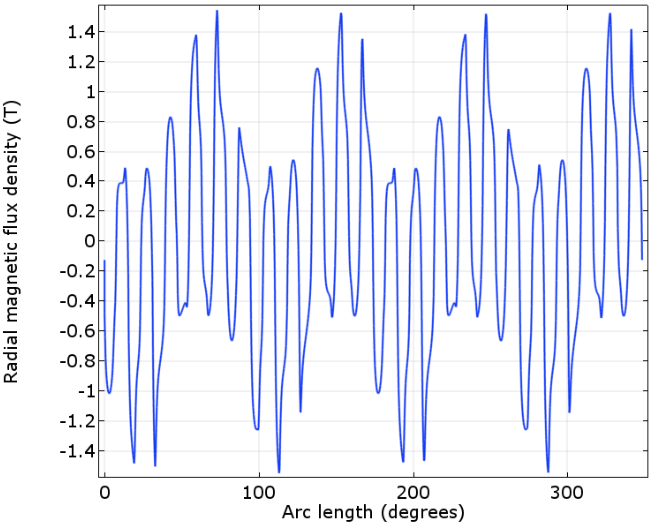

Fig. 2. Residual magnetic flux in air gap closer to low speed rotor.

II. SIMULATION STUDIES

A 2-dimensional magneto-static finite element method was made use of to achieve the simulation studies. The results were calculated for the first 45^0 of the rotation of the high speed rotor, the results for the whole model were extrapolated as the model is symmetric to reduce computation time and workload. The assumed parameters used in the simulations are as in Table I. Cobalt plated NdFeB permanent magnets have been used for both the low and the high speed rotor while steel laminations is used for the rotor cores and the stationary poles. COMOSL Multiphysics solver was us

A. Flux Density Distribution:

Fig. 2 shows the residual magnetic flux due to the low speed magnetic pole pairs in the air gap closer to the low speed rotor. It is evident that the presence of stationary steel poles produces an asynchronous space harmonic in the closest air gap interacting with the low speed rotor with 22 magnetic pole pairs. Rotational velocity at which the low speed rotor transmits torque is given by:

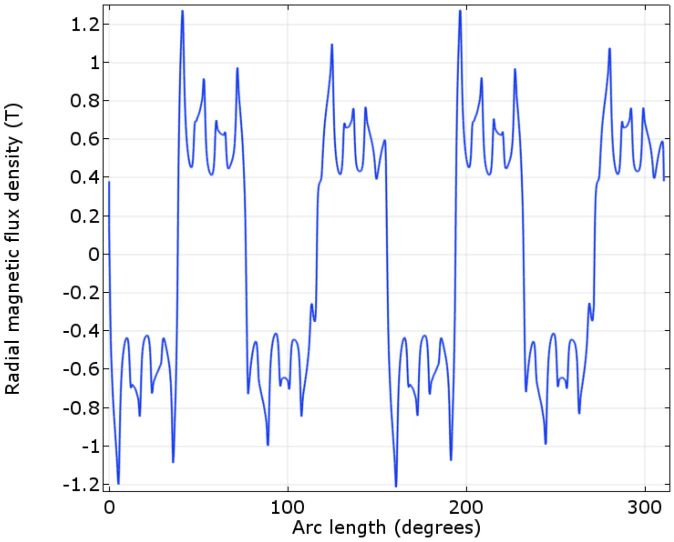

Fig. 3. Residual magnetic flux in air gap closer to high speed rotor.

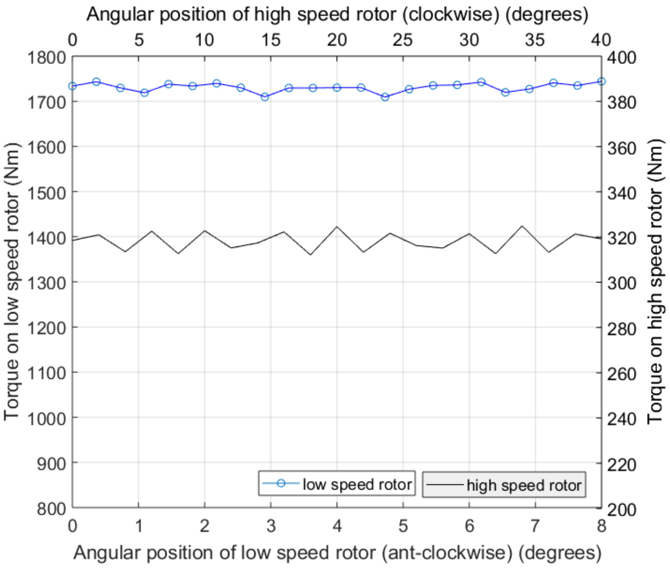

Fig. 4. Variation of torque on low and high speed rotor.

$$\omega_l = \frac{p_h}{p_h - n_s}\omega_h = -\frac{1}{5.5}\omega_h \tag{3}$$

Where ω_l and ω_h are the rotational velocities of low speed and high speed rotors respectively.

Fig. 3 shows the residual magnetic flux due to high speed magnetic pole pairs in the air gap closer to the high speed rotor. It is evident that the presence of stationary steel poles produces an asynchronous space harmonic in the closest air gap interacting with the low speed rotor with 4 magnetic pole pairs. Rotational velocity at which the high speed rotor transmits torque is given by:

$$\omega_h = \frac{p_h - n_s}{p_h}\omega_l = -5.5\ \omega_l \tag{4}$$

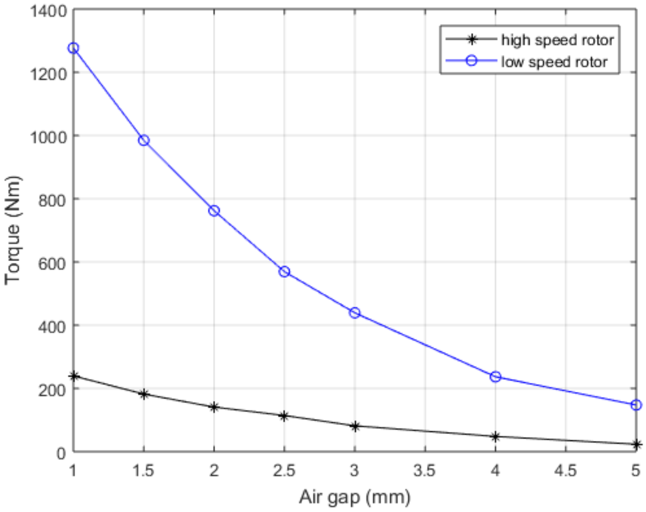

Fig. 5. Parametric study with varying air gap

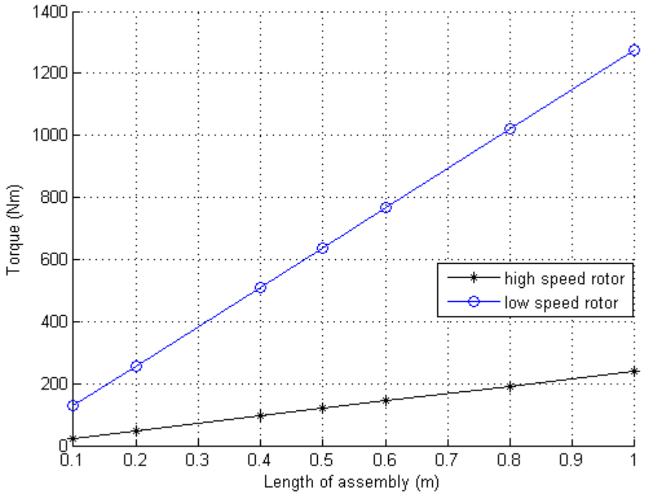

Fig. 6. Parametric study with varying length of assembly

B. Torque Transmission:

Fig. 4 shows the maximum torque being exerted on both low and high speed rotor as they operate in their own direction. A slight variation in the torque exerted on the rotors is observed due to the interaction of space harmonic of one present on one side of the stator poles with the space harmonic present on the other side of the stator poles through the stator poles. The presence of stator poles is very important as it acts as a gear between the outer lower speed rotor and the inner high speed rotor by modulation of flux densities available on both its sides [3].

III. PARAMETRIC STUDY

A parametric study was conducted with one of the factor among air gap, thickness of stator pole and length of assembly being varied and the other two factors kept as a constant throughout the study. Again, 2-dimensional magneto-static finite element method was made use of to achieve the outputs.

A. Varying air gap:

Fig. 5 is a plot of the maximum torque being experienced by the low speed and high speed rotors while the air gap was varied gradually from 1 mm to 5 mm. It is evident that an air gap of 1 mm allows maximum transmission of torque. Torque transmission decreases with the increase in air gap.

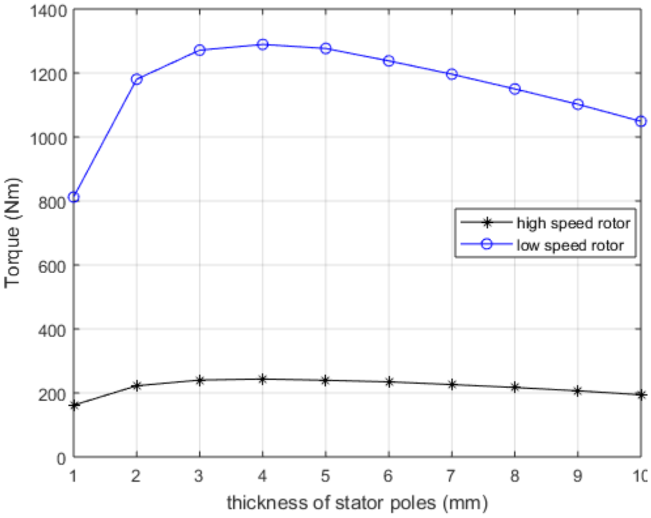

Fig. 7. Parametric study with varying thickness of stator poles

B. Varying length of assembly.

Fig. 6 is the plot of maximum torque being exerted on both the rotors as they rotate, it is evident that the maximum torque experienced by the rotors increases linearly with the increase in effective length of interaction of the magnetic field.

C. Thickness of stator poles

Simulations carried out with air gap as 1 mm, length of assembly as 0.1 m and the thickness of stator poles were varied from 1 mm to 10 mm. The result is shown in the Fig. 7. It can be seen that the torque on both the shafts increases with the increase in thickness of stator poles and is maximum when the thickness of stator poles is 5mm, torque transferred decreases with further increase in thickness of stator poles.

IV. CONCLUSIONS

The basic concept of operation of a magnetic gear is studied and has been understood. A combination of parameters has been chosen and the simulation study has been carried out using the same. Further, multiple parametric studies were carried out to determine the effects of parameters such as air-gap, thickness of stator poles and the effective length of assembly on the torque transmission capability of the magnetic gear and following are the inferences:

a. Maximum torque experienced by both the rotors is maximum when the air gap is 1 mm.
b. Maximum torque experienced by both the rotors is maximum when the thickness of stator poles is 5 mm.
c. Maximum torque experienced by both the rotors increases with the increase in effective length of the magnetic gear.

V. FUTURE SCOPE

A prototype will be manufactured using the parameters stated in Table I and further studies will be conducted on the prototype. Finally the results obtained by the operation of prototype will be compared to the results obtained from simulation study.

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