IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 4 Ser. III (Jul. - Aug. 2019), PP 51-56
www.iosrjournals.org

Design and Experimental Analysis of Axial Magnetic Coupling

Supriya S Waghulde [1], Kiran C More [2]
[1](*ME Student, Mechanical Engg Dept., D Y Patil Institute of Technology and Engineering, Pune, India*)
[2](*Associate Professor, Mechanical Engg. Dept., D Y Patil Institute of Technology and Engineering , Pune, India*)
Corresponding Author: Supriya S Waghulde

Abstract: *Magnetic coupling can transmit the torque from driving to driven shaft without any mechanical contact leading to minimization of energy loss. hence it is preferred in industrial applications where isolated systems are used. This paper deals with the design optimization of coupling by varying number of poles and thickness of magnet mounted disc and further analyzed analytically and is compared for both the cases and results are validated experimentally.*

Date of Submission: 06-08-2019 Date of acceptance: 22-08-2019

I. Introduction

A mechanical device which helps to transmit the torque from driving to driven part is called Mechanical Coupling. Normally shaft doesn't disconnect in normal operating condition, however there are some coupling which do disconnect or slip away beyond a particular torque limit is reached. To avoid this Magnetic Coupling are used where torque is transmitted without any mechanical contact. It has the ability to protect system against overload condition as well as transfer torque even in misalignment. Magnetic coupling are of two types synchronous and induction type. In Synchronous type magnetic coupling the two disc, each consists of sector shaped permanent magnet separated with small air gap while in Induction type magnetic coupling one disc is mounted with sector-shaped permanent magnet while the other disc is mounted with copper plate, separated by a small air-gap. The magnets are axially magnetized to obtain alternate north and south poles. Soft-iron yoke are used to close the flux and due to the magnetic induction the torque is transferred through an air-gap from one disc to other disc. Above figure shows axial Magnetic coupling structure, having circular shaped neodymium magnets mounted on driving disc along the circumference of the disc, while copper plate is mounted on driven disc. A permanent magnets is an object made from a material that is magnetized and creates its own magnetic field. Mounted on mild steel driving shaft.

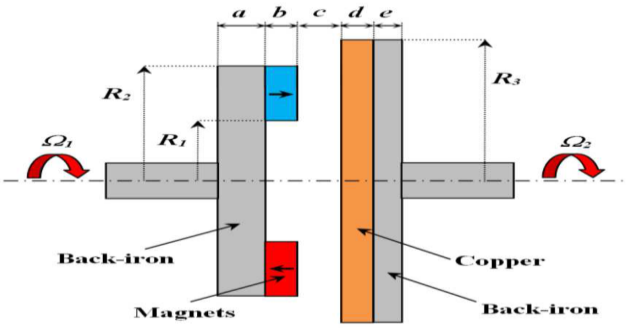

Fig1: Axial magnetic coupling structure

Which further induces magnetic field to driven disc which leads to transfer of torque. Copper disc is mounted on driven shaft. mild steel disc are used to closed the flux and hold the magnets. And air gap of 3mm is considered between the disc. Inner radius of disc R1. Outer radius of disc R2 on which magnets are mounted. Outer Radius of Copper plate R3. a is the thickness of the back-iron (magnets side), b the magnets thickness, c the air-gap length, d the thickness of the copper plate, e the thickness of the mild steel (copper side). The pole-arc to pole-pitch ratio of magnets is α, and p is the pole-pairs number [2]. The mean radius of the torque coupler is defined as Rm = (R1+R2)/2.

II. Initial Design Parameters And Design Aspects

In induction type Magnetic coupling, the electromagnetic field and the temperature field are interactive. Due to electromagnetic induction there is eddy current loss due to which temperature on the copper surface increases and in return due to temperature rise it affect the electromagnetic field distribution. So while designing of this coupling it is important to consider eddy current loss which leads to decrease in electric conductivity of copper which further leads to decrease in output torque. Also, one of the factor should be considered is the thickness of metal disc where magnetic saturation is developed. It is the condition reached when external magnetic field cannot increase the magnetisation of material and hence the overall magnetic flux density levels of. When the magnetic saturation is meet the magnetic flux produced by the magnet will keep on increasing and due to saturation the magnetic flux induced will remain constant and hence the total flux which is to be induced to the driven disc won't increase. hence the torque will remain constant after repeated trial beyond the magnetic saturation limit, the driven disc wont be able to sustain the developing magnetic flux and it would start wobbling. Hence it is important to consider the thickness of magnet mounted disc during designing phase.

Table1: Initial Design parameters

Sr.no	Variables	Units	Values
1.	Outer Radius of disc R2	cm	6.5
2	Inner Radius of disc R1	cm	4
3	Radius of copper disc R3	cm	7
4	Magnet Thickness b	mm	10
5	Copper plate thickness d	mm	8
6	Pole arc to pitch ratio (α)	-	0.76
7	Number of poles (p)	nos.	6
8	Thickness of mild steel disc (a)	mm	10

As shown in table 1, Considering above dimensions to obtain 50Nm torque, with 6 number of magnets.R3 is calculated in order to permit a return path of the induced currents by R3 = R2+τ/2. Where $\tau = \frac{\pi}{p}$ Rm. and Rm is a mean radius of driving disc. The remanence of magnets Br is equal to 1.4 T, and the conductivity of copper is 57 MS·m−1.The considered operating condition is, at load power of 0.5 hp.

III. ANALYTICAL CALCULATION

Torque is obtained using 3D Analytical model considering mean radius. Analytical Calculation is done using 3D Maxwell equation, where initial and after optimized parameters are considered.

3D Maxwell Torque equation is given by:

$$Te = \frac{1}{2}\mu p^2 \tau R_3 + \sum_{n=1}^{n}\left(jk\frac{M^2}{a_{nk}} r \sinh(a_{nk} b\right) \text{---------(1)}$$

$$\tau = \frac{\pi}{p} R_m \text{ ------(2)}$$

$$M_{nk} = \frac{16B_r}{\pi^2 \mu\, nk}\sin\left(\frac{k\alpha\pi}{2}\right)\sin(\frac{n\pi}{2}.\frac{R_2-R_1}{R_3}) \text{ -------(3)}$$

$$a_{nk} = \sqrt{\left(\frac{n\pi}{R_3}\right)^2 + \left(\frac{k\pi}{\tau}\right)^2} \text{ ----(4)}$$

Where, α is pole pitch to arc ratio, Rm is the mean radius. From above equation it has been observed that torque is dependent upon number of poles, thickness of disc, inner and outer radius of magnet mounted disc and considered as an design parameter during torque calculation in APMC.

Case I: It has been observed that, for 6 number of poles and 10mm thickness at air gap of 3mm, the output torque obtained is 45.87 Nm. Which is less than required torque of 50Nm and it is due to the saturation effect in magnet mounted disc and number of magnetic poles in contact, to improvise the results it is important to optimize the coupling.

For Optimization, Jaya algorithm is used. It is capable of solving both constrained and unconstrained optimization problems. It is a population based method which repeatedly modifies a population of individual solutions. Can be solved in short duration and it is implemented using MATLAB [12].

Table 3: Optimized results using Jaya Algorithm

Sr. No	Variables	Units	Before Optimization	After Optimization
1	Radius of disc R2	cm	6.5	6.5
2	Radius of disc R1	cm	4	4
3	Radius of Copper disc R3	cm	7	7
4	Air Gap	mm	5	3
5	Magnet thickness b	mm	10	10
6	Copper plate thickness (d)	mm	8	8
7	Pole arc/pole pitch ratio (α)	-	0.36	0.48
8	No. of poles (p)	nos.	6	8
9	Thickness of disc magnet side (a)	mm	10	8

Case II: By considering optimized value, i.e number of poles of 8 numbers and thickness of magnet mounted disc of 8mm and for air gap of 3mm and further solving analytically, the output torque obtained is 52 Nm which is greater than torque boundary condition.

IV. NUMERICAL ANALYSIS

For design of axial magnetic coupling it is important it satisfies the given boundary condition with proper design parameters such as magnet height, air-gap length, inner radius of disc, outer radius of disc, iron yoke thickness, and pole numbers. The 3-D model of axial magnetic coupling is constructed in Catia V5 and its .igs file is further imported to Comsol for Torque analysis.

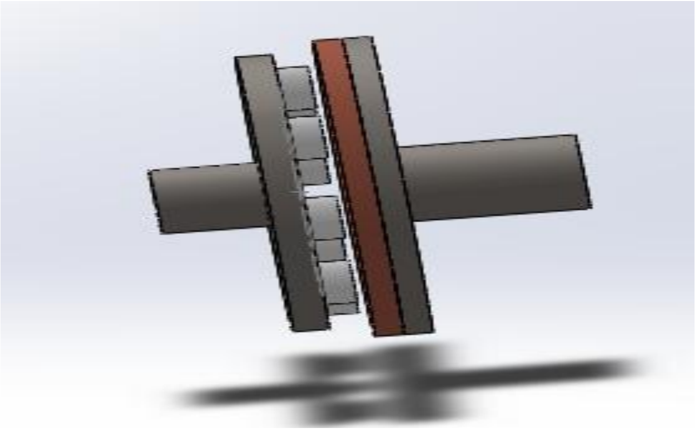

Fig 2: 3-D Model of magnetic coupling in Catia V5

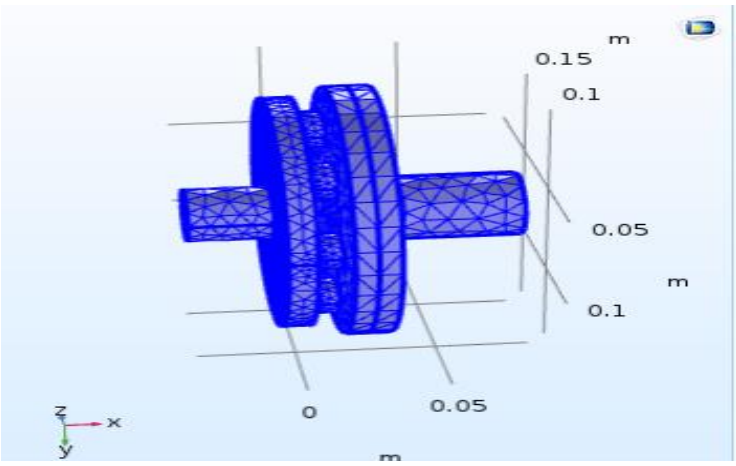

Fig 3: After meshing and applying physics to magnetic coupling in Comsol

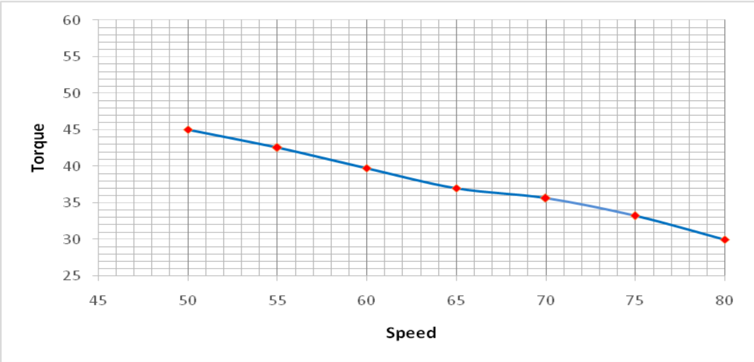

Fig 4: Before Optimization results in Comsol

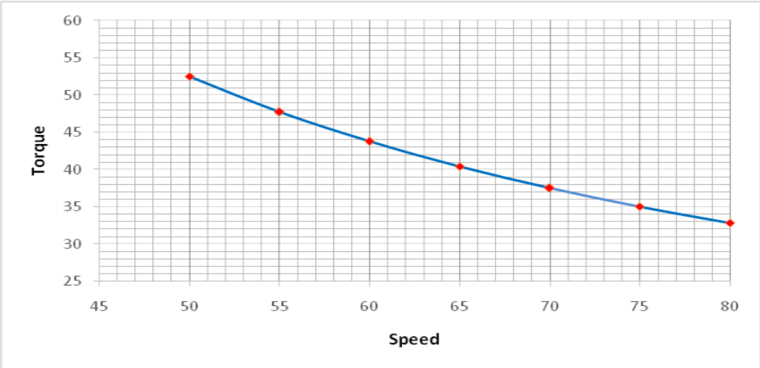

Fig 5: After Optimization results in Comsol

FEA analysis is performed for both before optimization condition and after optimization condition and it has been observed that, before optimization the toque obtained is 44.02 Nm and after optimization the torque obtained is 53.2 Nm.

V. Experimental Setup And Result

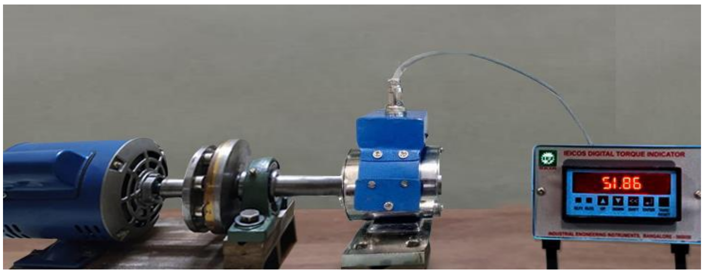

Fig 6: Experimental setup

As shown in above figure 6, an axial magnetic coupling is fabricated using circular type NdFeB magnets glued on mild steel disc. One disc of magnetic coupling is mounted on shaft of DC motor which is also known as driving shaft and second disc of copper plate is mounted on another mild steel disc which is fixed mounted on footstep bearing. Further the coupling is connected to torque transducer and torque is measured in both conditions. i.e before optimization and after optimization and the final output torque obtained after optimization is 51.86 Nm which satisfies the requirement.

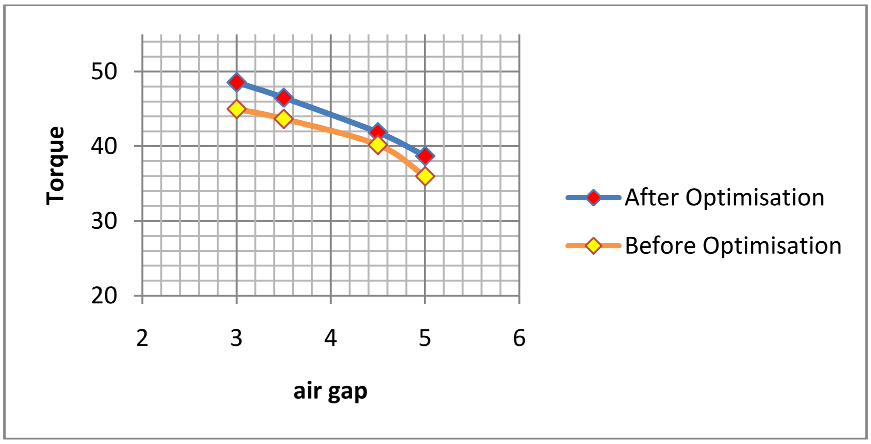

Fig 7: Torque versus variable value of air gap

The above graph of Torque versus variable values of air gap is plotted for both after and before optimization conditions i.e for before optimisation number of poles 6 numbers and disc thickness of 10mm and for after optimisation the number of poles 8 numbers and disc thickness of 8mm is considered and for variable values of air gap Torque is measured, and it has been observed that with decrease in air gap Torque increases.

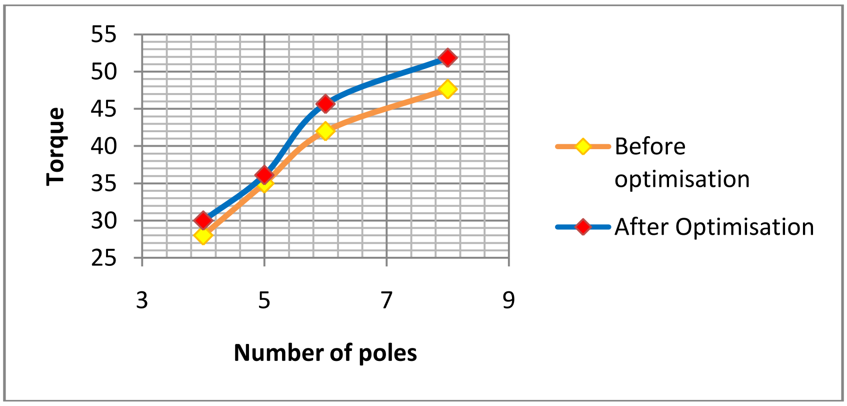

Fig 8: Torque versus Number of poles

The above graph is plotted for both before and after optimization condition i.e for before optimization the disc thickness is of 10mm and after optimization disc thickness is of 8mm for air gap of 3mm, and Torque value is obtained for variable value of number of poles and it has been observed that as the number of poles increases i.e with the increase in Volume of magnet, the torque also increases.

Table 2: Result Comparison

Torque (Nm)	Analytical Results	FEA Results	Experimental Results
Before Optimization	41.37	44.02	40
After Optimization	52	53.2	51.86

VI. CONCLUSION

Have considered induction type magnetic coupling, It has been observed that according to initial design parameters the Torque value analytically is 41.37 Nm, Finite element results are 44.02 and experimental result are 40 Nm . The design of Magnetic coupling is further optimized using Jaya algorithm considering all the design parameters and solved analytically and finite element analysis is carried out and further validated experimentally to study the effect of this parameters to satisfy the required problem statement. Now according to new design experimental results obtained is 51.86 Nm and Analytical results obtained is 52 Nm and finite element result are 53.2 Nm. And hence it has been observed that torque is improved considering optimized parameter and hence the problem statement to maximize torque is validated

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