Design, Development, and Testing of Axial Magnetic Coupling for Pump

Maruti M. Khot[1], Pavan G. Jadhav[2], Sana M. Bagwan[3]

[1]Assistant Professor, Department of Mechanical Engineering, Walchand college of engineering, Sangli-416415, India.

[2]PG Student, Department of Mechanical Engineering (M-Tech design) Walchand college of engineering, Sangli-416415, India.

[3]PG Student, Department of Mechanical Engineering (M-Tech design) Walchand college of engineering, Sangli-416415, India.

***Abstract**: A pump is a device used to move a fluid from one place to another by converting mechanical energy into hydraulic energy. A coupling is a device that transfers power from one shaft to another. The purpose of a joint is to connect two parts while allowing some degree of displacement, finite movement, or both. However, in a normal connection, there are many losses such as mechanical, noise and vibration etc. These losses affect the efficiency of the system. Mechanical seals may leak cause leakage of hazardous chemicals that pollute the environment which must be prevented. Mechanical seals limit the speed of the pump because the amount of seal wear is proportional to the speed. Magnetic coupling is introduced to increase coupling efficiency and minimize mechanical coupling losses. A non-contact coupling transmits power from the input shaft to the output shaft without contact. Microsoft Excel is used for magnetic coupling design calculations. This article presents an evaluation of the forces and torques transmitted by magnetic couplings. Theoretical analysis of magnetic connections is carried out using basic principles of electromagnetics. Magnetic couplings are designed to withstand a given load and torque. Permanent disc magnets made of NdFeB material, N35 grade are chosen for magnetic coupling due to their high magnetic field strength. A gunmetal plate is used to hold the magnet.*

Keywords: Pump, Magnetic Coupling, NdFeB Magnet, Statistical Analysis.

1. Introduction

The purpose of a coupling is to connect two parts that allow for some degree of misalignment, finite misalignment, or both. More generally, a coupling may also be a mechanical device for joining the ends of adjacent parts or objects. couplings usually prevent the shaft from disengaging during operation, but there are torque limiting couplings that can slip or disengage when some torque limit is exceeded. Coupling selection, installation, and maintenance can reduce maintenance time and cost.

Magnetic couplings are of great interest in many industries. Torque can be transmitted from the main drive to the slave without mechanical contact because torque can be transmitted through the baffle, axial magnetic field couplings are suitable for use in insulating systems such as vacuum vessels or pressure vessels. It also provides a maximum transfer torque (shutdown torque) that provides internal overload protection.

Axial magnetic coupling consists of two opposing discs mounted with NdFeB permanent magnets. Magnets are axially magnetized. They are designed to receive alternating north and south poles. The flow is closed with a stainless-steel plate. Torque applied to one disc is transmitted to the other disc through the air gap. Each movement between the two discs depends on the value of the transmitted torque. The main disadvantage of axial magnetic coupling is that there is a significant axial attraction between the two discs.

2. Design of an axial magnetic coupling

Designing a magnetic coupling requires knowledge of electromagnetism. Maxwell's equations are the basic governing equations in electromagnetism.

$$\vec{\nabla}.\ \vec{E} = \frac{\rho}{\epsilon_0} \quad (1)$$

$$\vec{\nabla} \cdot \vec{B} = 0 \quad (2)$$

$$\vec{\nabla} \times \vec{E} = \frac{\partial B}{\partial t} \quad (3)$$

$$C^2 \vec{\nabla} \times \vec{B} = \frac{\partial E}{\partial t} + \frac{j}{\epsilon_0} \quad (4)$$

In magnetostatics Equation (1) to Equation (4) equations boils down to

$$\vec{\nabla} \cdot \vec{B} = 0 \quad (5)$$

$$C^2 \nabla \times B = \frac{j}{\epsilon_0} \quad (6)$$

Here j can be divided in 3 components: polarization component (jpol), magnetization component (jmag) and conduction component (jcond).

$$j = jpol + jmag + jcond \quad (7)$$

$$C\,2\nabla \times B = \frac{jpol + jmag + jcond}{\epsilon_0} \quad (8)$$

$$jmag = \nabla \times M \quad (9)$$

$$jpol = 0 \quad (10)$$

From Equation (9) and Equation (10) we can simplify the equation.

$$C\,{}^2\nabla \times \left(B - \frac{M}{C\,2\epsilon 0}\right) = \frac{jcond}{\epsilon 0} \quad (11)$$

Now we can define H as

$$H = \epsilon 0\ C\,2B - M \quad (12)$$

$$\mu 0 = \frac{1}{\epsilon 0\ C\ 2} \quad (13)$$

In the current problem, the second is also 0. Thus, our new governing equations for the considered problem are

$$\nabla \times H = 0 \quad (14)$$

$$\nabla.\ B = 0 \quad (15)$$

$$B = \mu_0(H + M) \quad (16)$$

In free space, the above equation would look like

$$B = \mu_0(H) \tag{17}$$

because M would be 0 anywhere other than magnets. To solve for Magnetic field B we assume

$$H = \nabla \emptyset m \tag{18}$$

Substituting Equation (16) in Equation (15) we get

$$\nabla 2\emptyset m + \nabla.\mathrm{M} = 0 \tag{19}$$

On solving Equation (19) we $\emptyset m$ obtain as

$$\emptyset m(X) = \frac{1}{4\pi} \int_v \frac{\nabla'.\mathrm{M}(\mathrm{x}')}{|\mathrm{x} - \mathrm{x}'|} \mathrm{dv}' \tag{20}$$

Applying Gauss divergence on Equation (20) we get

$$\emptyset m(X) = \int_s \frac{\mathrm{M}(\mathrm{x}')\, n}{|\mathrm{x} - \mathrm{x}'|} \mathrm{ds}' \tag{21}$$

Using Equation (17), Equation (18), and Equation (21) we obtain the expression for B.

$$B(X) = \frac{1}{4\pi} \int_s \frac{\mathrm{M}(\mathrm{x}')\, n}{|\mathrm{x} - \mathrm{x}'|} \mathrm{ds}' \tag{22}$$

A detailed derivation of the same is done by John Davis Jackson

In electromagnetism, force is generally given by:

$$F = q\,(E + v \times B) \tag{23}$$

But in this context, it can be written as

$$F = \int_V (\mathrm{J} \times \mathrm{B})\,\mathrm{dV} + \int_A (\mathrm{j} \times \mathrm{B})\,dA \tag{24}$$

And torque transmitted by the coupling is given by:

$$T = \int_V \mathrm{rsin}(\mathrm{p}\delta) \times (\mathrm{J} \times \mathrm{B})\,\mathrm{dV} \int_A \mathrm{rsin}(\mathrm{p}\delta \times (\mathrm{j} \times \mathrm{B})\,dA \tag{25}$$

$$J = \nabla \times \mathrm{M} \tag{26}$$

$$j = M \times n \tag{27}$$

All the formulations presented till now are generic, when solved for respective geometries an expression of force and torque can be obtained for axial coupling. The final expression for axial [1] coupling was established and results were presented based on it. Furlani et. al[1] have also dealt in detail with the mathematics behind magnetic field calculation for radial coupling. On similar lines, calculations for axial coupling were also performed.

In axial magnets, the magnetization is assumed to be constant and in the axial direction. thus, from Equation (26), it can be seen that J will turn out to be 0 in axial the cases, transforming Equation (24) as

$$F = \int_A (\mathrm{j} \times \mathrm{B})\mathrm{dA} \tag{28}$$

and Equation (25) as

$$T = \int_V \mathrm{rsin}(\mathrm{p}\delta) \times (\mathrm{j} \times \mathrm{B})\mathrm{dA} \tag{29}$$

To obtain the torque of axial coupling the only relevant components required are Ft, Tz, and Bz. This simplifies Equation (22) t

$$Bz\,(X) = \frac{1}{4\pi} \int_S \frac{\mathrm{Mzd}}{(|\mathrm{x} - \mathrm{x}'|)^3} \mathrm{ds}' \tag{30}$$

Here S refers to the axial surface of the axial coupling. Substituting Equation (30) in Equation (28) we get

$$Ft\,(X) = (Mz \times Bz\,(X)) \tag{31}$$

Where A is the circumferential area of the axial magnet.

Now substituting Equation (31) and Equation (28) in Equation (29) we get

$$Tz = \int_A (\mathrm{rsin}(\mathrm{p}\delta) \times \mathrm{Ft}\,(\mathrm{X}))\mathrm{dA} \tag{32}$$

where r is the radial distance till point x and A is a circumferential area of axial coupling.

3. Experimental setup

As shown in above figure 1, an axial magnetic coupling is fabricated using circular type NdFeB magnets glued on a gunmetal plate. One plate of magnetic coupling is mounted on the shaft of the DC motor which is also known as the driving shaft and the second plate is mounted on another propeller shaft also known as the driven shaft.

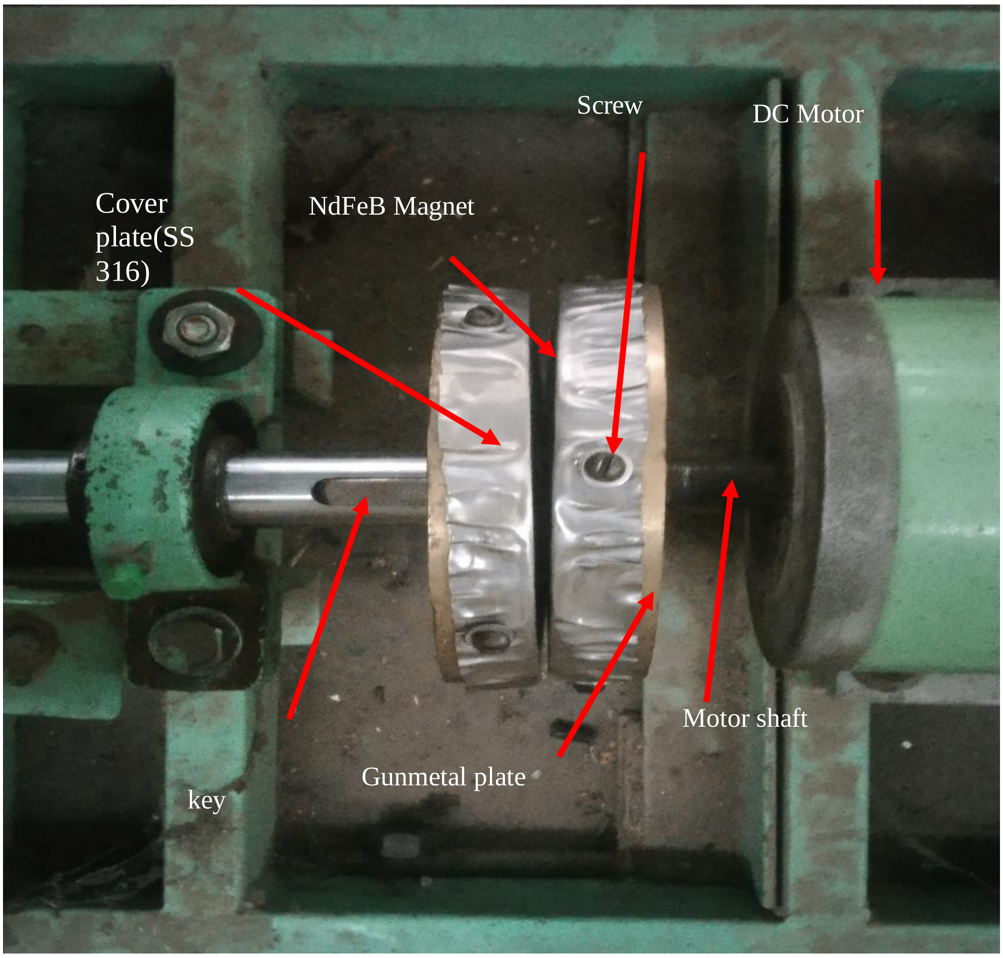

Figure 1 Experimental setup

4. Results and discussion

For given 1 hp power input torque transmitted by the coupling at 1440 rpm is 4.94 N-m for factor safety as 1.5 the required torque to be transmitted at the power of 1 hp will be 7.41N-m. As per the manufacturing constraint, we choose the 120mm dia. of the disc plate of gunmetal where magnets are place in a circular pattern. For magnetic coupling 8 magnets and diameter of each 25mm and thickness is 6mm, there is 5mm gap between two plates. For a given plate, input power and rpm coupling can transfer the net torque of 13.28 N-m and tangential force of 44.29N using theoretical analysis. Hence the torque requirement of the pump is fulfilled.

From experimental results obtained the force and torque transmitted by magnetic coupling are mainly affected by the air gap between plates. The variation of force and torque concerning air gap is shown in figure 3 and figure 4 respectively. The force and torque are varying as negative cubic concerning the mental gap.

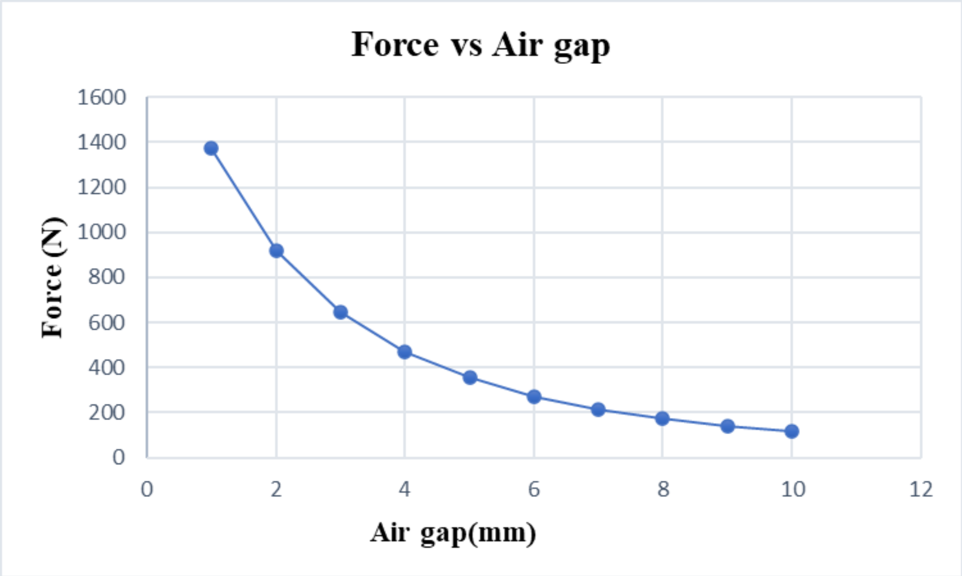

Figure 2 Force vs air gap between magnets

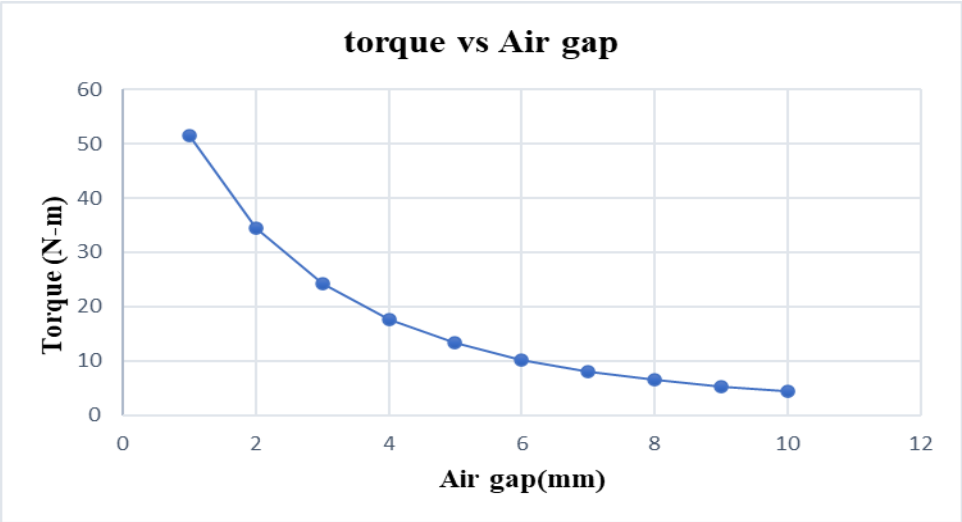

Figure 3 Torque vs air gap between magnets

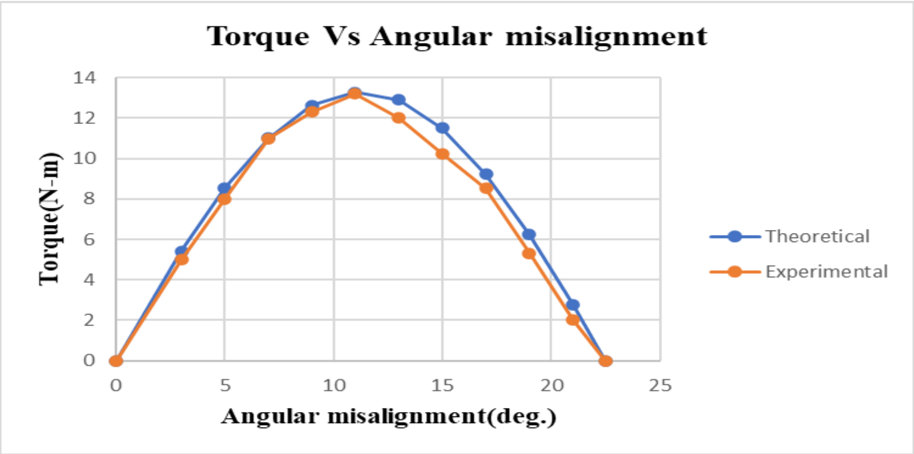

Figure 2 Torque vs angular misalignment for a distance of 5mm between the magnets

By comparing the experimental result and analytical values obtained, when air gap between plates is 5 mm. found error between experimental result and analytical values is 8.48%.

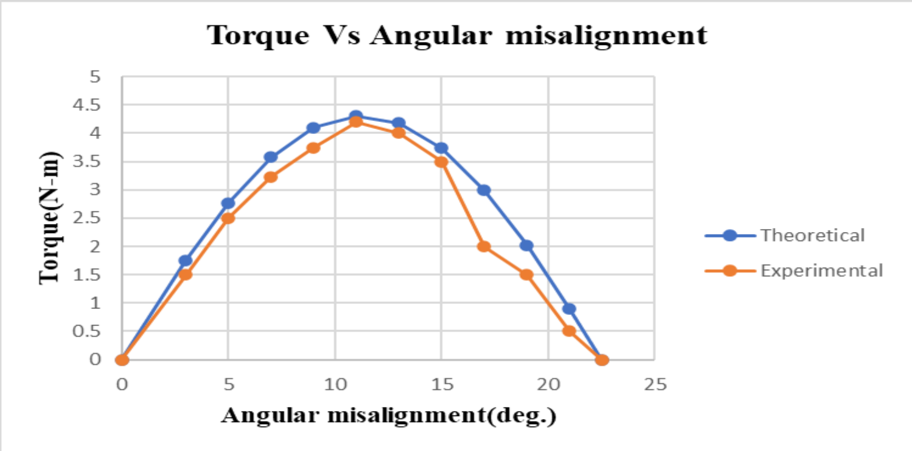

Figure 3 torque vs angular misalignment for a distance of 10mm between the magnets

By comparing the experimental result and analytical values obtained, when air gap between plates is 10 mm. found error between experimental result and analytical values is 13.24%.

5. Conclusion

The Maxwell equations are used for theoretical analysis. The experimental results obtained are used to calculate torque transmission by coupling for given rpm and input power. The torque transmitting capacity of the coupling is affected by several factors like magnetic poles, angular misalignment, the distance of magnets from the center of plates, and the air gap between the two magnets. As an increase in air gap distance between two magnets, torque transmitting capacity decreases exponentially. As the pitch circle radius of disc magnets from the center of the gunmetal plate increases, the torque transmitting capacity of the coupling increases linearly. As the number of magnets of the magnetic coupling increases the torque transmitting capacity also increases. For the value of 11.25 misalignment we get max. torque transmission of coupling.

Acknowledgments

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