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Design of Axial Magnetic Coupling for Compressor

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Abstract: A mechanical device which raises the pressure of a gas by decreasing its volume is called as compressor. A coupling is a device which transmits the power from one end to another end. The purpose of coupling is to join two parts which allowing some degree of misalignment or end movement or both. But in conventional coupling, there are lots of losses like mechanical losses, noise and vibration losses etc. These losses have effects on the efficiency of the system. In mechanical seals, leakages are possible. So, leakage of hazardous chemicals polluting the environment has to prevent. The mechanical seal limits the speed of the compressor as the wear rates of the seal are proportional to speed. To improve the efficiency of coupling and to minimize the mechanical losses of coupling, magnetic coupling is introduced. It is contactless coupling which transfer the power from input shaft to output shaft. MATLAB software is used for analysis of magnetic coupling. This paper represents evaluation of force and torque transmitted by magnetic coupling. The theoretical analysis of magnetic coupling is carried out by using basic principle of electromagnetism. Magnetic coupling is designed to sustain the given load and torque. Permanent disc magnets of NdFeB material are selected for magnetic coupling for high strength of magnetic field. The brass plates are used to hold the magnets.
Keywords: Compressor, magnetic coupling, MATLAB simulation, NdFeB Magnet.

I. INTRODUCTION

The purpose of coupling is to join two parts which allowing some degree of misalignment or end movement or both. In a more general context, a coupling can also be a mechanical device that serves to connect the ends of adjacent parts or objects. Couplings do not normally allow disconnection of shafts during operation, however there are torque-limiting couplings which can slip or disconnect when some torque limit is exceeded. Selection, installation and maintenance of couplings can lead to reduced maintenance time and maintenance cost.

A. Centrifugal Compressors

Centrifugal compressor is a device which sucks the air from suction line and discharge the air from discharge line. Centrifugal compressors are more suited for continuous-duty applications such as ventilation fans, air movers, cooling units, and other uses that require high volume but relatively low pressures.

B. Neodymium (NdFeB) Permanent Magnets

Neodymium magnets are also known as rare earth magnet. Neodymium magnets are permanent magnets made from an alloy of neodymium, iron and boron to form the Nd2Fe14B tetragonal crystalline structure. These are developed first time in 1984. Neodymium magnets are the strongest type of permanent magnets available commercially. Some commercial examples of neodymium magnets are Hard disk drives (HDDs) for computers, Door Locks, Electric Generators, Power Steering, Speakers and Headphones etc. Neodymium magnets are divided in various grade according to their strength of magnetization. They are available from N35 to N52 grades. N is the standard and number followed by N shows grade. Higher the grade, stronger the magnet. If any letter is given followed by number, then it represents temperature rating of the magnet. If no letter is given after the numbers, it is standard neodymium magnet. With the help of B-H curve, magnetic material will be determined.

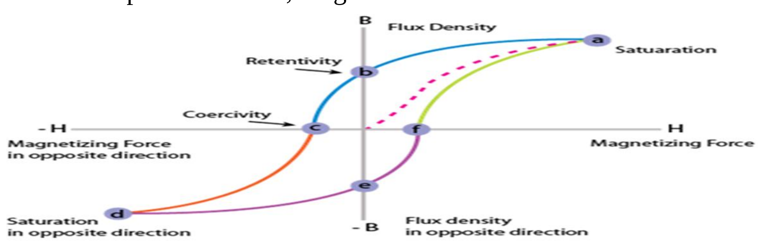

Fig.1: B-H curve for magnetic material [4]

From catalogue of magnets, consider the disc magnet of N35 grade having remanence 1.20 T and coercive force 868 KA/m min at working temperature of 80°C.

C. Magnetic Coupling

Magnetic coupling is a device which transmits the power from one shaft to other shaft without in any contacts of moving parts. Neodymium disc magnets are plays main role for their contactless transmission. Those disc magnets are placed on non-magnetic (brass) plates in circular manner with alternate direction of magnetic poles.

II. DESIGN OF AXIAL MAGNETIC COUPLING

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

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

$$\nabla \times E = \frac{\partial B}{\partial t} \quad (2)$$

$$\nabla . \mathrm{B} = 0 \quad (3)$$

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

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

$$\nabla . \mathrm{B} = 0 \quad (5)$$

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

Here **j** can be divided in 3 components: polarization component ($\mathbf{j}_{pol}$), magnetization component ($\mathbf{j}_{mag}$) and conduction component ($\mathbf{j}_{cond}$).

$$j = j_{pol} + j_{mag} + j_{cond} \quad (7)$$

So, the equation becomes

$$C^2 \nabla \times \mathrm{B} = \frac{j_{pol} + j_{mag} + j_{cond}}{\epsilon_0} \quad (8)$$

Here

$$j_{mag} = \nabla \times M \quad (9)$$

$$j_{pol} = 0 \quad (10)$$

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

$$C^2 \nabla \times \left(\mathrm{B} - \frac{\mathrm{M}}{\epsilon_0 C^2} \right) = \frac{j_{cond}}{\epsilon_0} \quad (11)$$

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Now we can define **H** as

$$H = \epsilon_0 C^2 B - M \tag{12}$$

$$\mu_0 = \frac{1}{\epsilon_0 C^2} \tag{13}$$

In the current problem $\mathbf{j}_{cond}$ is also 0. Thus, our new governing equations for the considered problem are

$$\nabla \times H = 0 \tag{14}$$

$$\nabla . \mathrm{B} = 0 \tag{15}$$

$$B = \mu_0 (H - M) \tag{16}$$

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 obtain φ_m as

$$\emptyset_m (X) = \frac{1}{4\pi} \int_V \frac{\nabla' . M(X')}{|X - X'|} dV' \tag{20}$$

Applying Gauss divergence on Equation (20) we get

$$\emptyset_m (X) = \frac{1}{4\pi} \int_S \frac{M(X') . n}{|X - X'|} dS' \tag{21}$$

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

$$B(X) = \frac{\mu_0}{4\pi} \int_S \frac{(M(X') . n)(X - X')}{(|X - X'|)^3} dS' \tag{22}$$

In electromagnetism force is generally given by:

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

But in this context, it can be written ass

$$F = \int_V (J \times B) dV + \int_A (j \times B) dA \quad (24)$$

And torque transmitted by the coupling is given by:

$$T = \int_V r \times (J \times B) dV + \int_A r \times (j \times B) dA \quad (25)$$

Where **J** is given as

$$J = \nabla \times \mathrm{M} \quad (26)$$

and **j** is written as

$$j = M \times n \quad (27)$$

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 coupling were established and results were presented based on it. Furlani et.al [1] have also dealt in detail the mathematics behind magnetic field calculation for radial coupling. On the similar lines calculations for axial coupling were also performed. In axial magnets, the magnetization is assumed to be constant and in 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

$$F = \int_A (j \times B) dA \quad (28)$$

and Equation (25) as

$$T = \int_v r \times (j \times B) dA \quad (29)$$

To obtain the torque of axial coupling the only relevant components required are F_t,T_z and and B_z. This simplifies Equation (22) to

$$B_z(X) = \frac{\mu_0}{4\pi} \int_S \frac{M_z d}{(\mid X - X' \mid)^3} dS' \quad (30)$$

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

$$F_t(X) = \left(M_z B_z(X)\right) \quad (31)$$

Where A is the circumferential area of the axial magnet.
Now substituting Equation (31) and Equation (28) in Equation (29) we get

$$T_z = \int_A \left(r F_t(X)\right) dA \quad (32)$$

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

III. RESULTS AND DISCUSSIONS

For given power input torque transmitted by the coupling for 1 hp power input at 1440 rpm is 4.94 N-m for considering factor safety as 2 the required torque to be transmitted at power of 1 hp will be 9.88N-m. As per the manufacturing constraint, we choose the 120mm dia. of disc plate of brass where magnets will place in circular pattern. For magnetic coupling assuming 8 discs of magnet and diameter of each disc 25mm also thickness of the disc is 6mm, there is 5mm gap between two plates. For given plate, power input and rpm coupling can transfer the net torque of 14.4 N-m and tangential force of 47.53N using theoretical analysis. Hence at this torque of 14.4 N-m powers requirement of the compressor is fulfilled.

From given theoretical analysis, we knew that force and torque transmitted by magnetic coupling mainly affected by air gap between plates. The variation of force and torque with respect to air gap are shown in figure 2 and figure 3 respectively. The force and torque are varying as negative cubic with respect to gap. Mathematical model is solved by using MATLAB programming. Also, the MATLAB programming used to plot the graph of variation of force and torque with respect to gap between two plates in magnetic coupling.

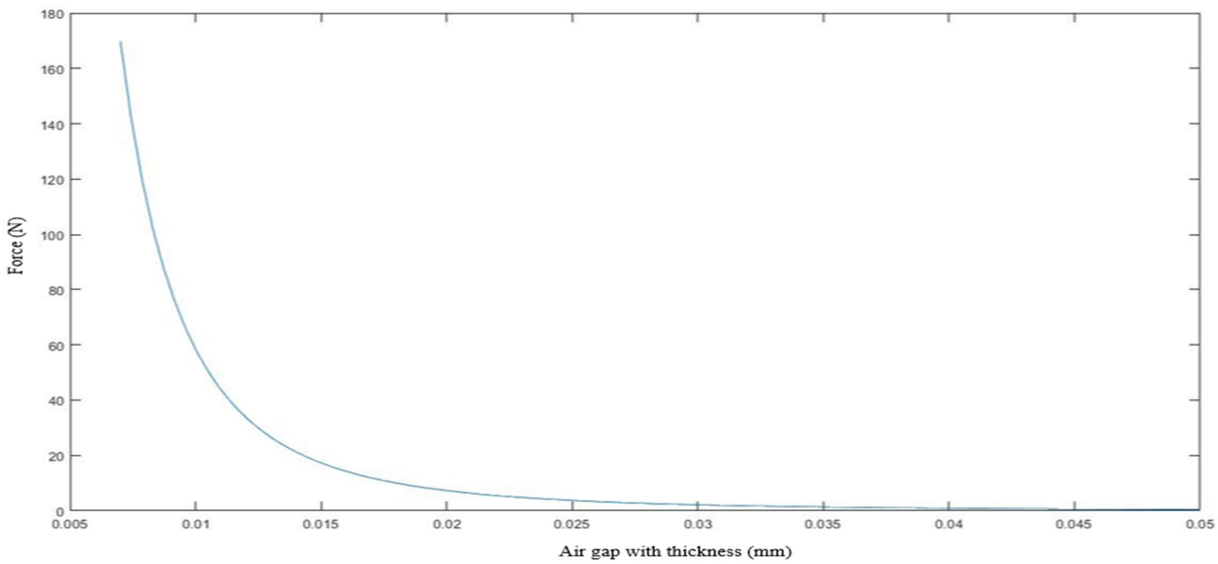

Fig. 2: Force vs. air gap with thickness

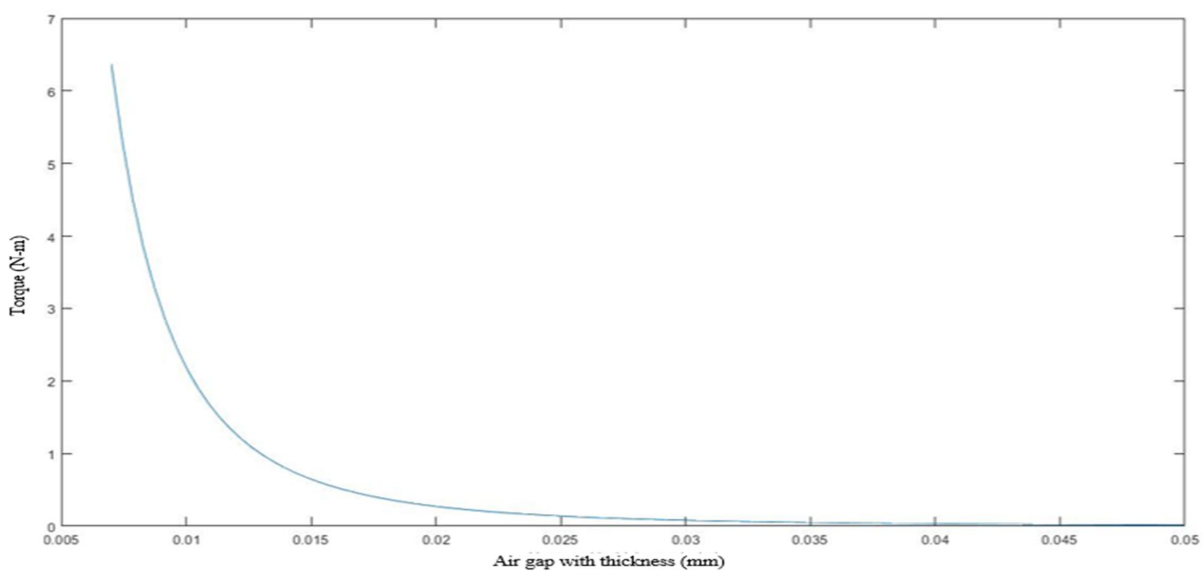

Fig. 3: Torque vs. air gap with thickness

After getting the values from the theoretical analysis, a 3-D model is drawn with the help of CATIA software.

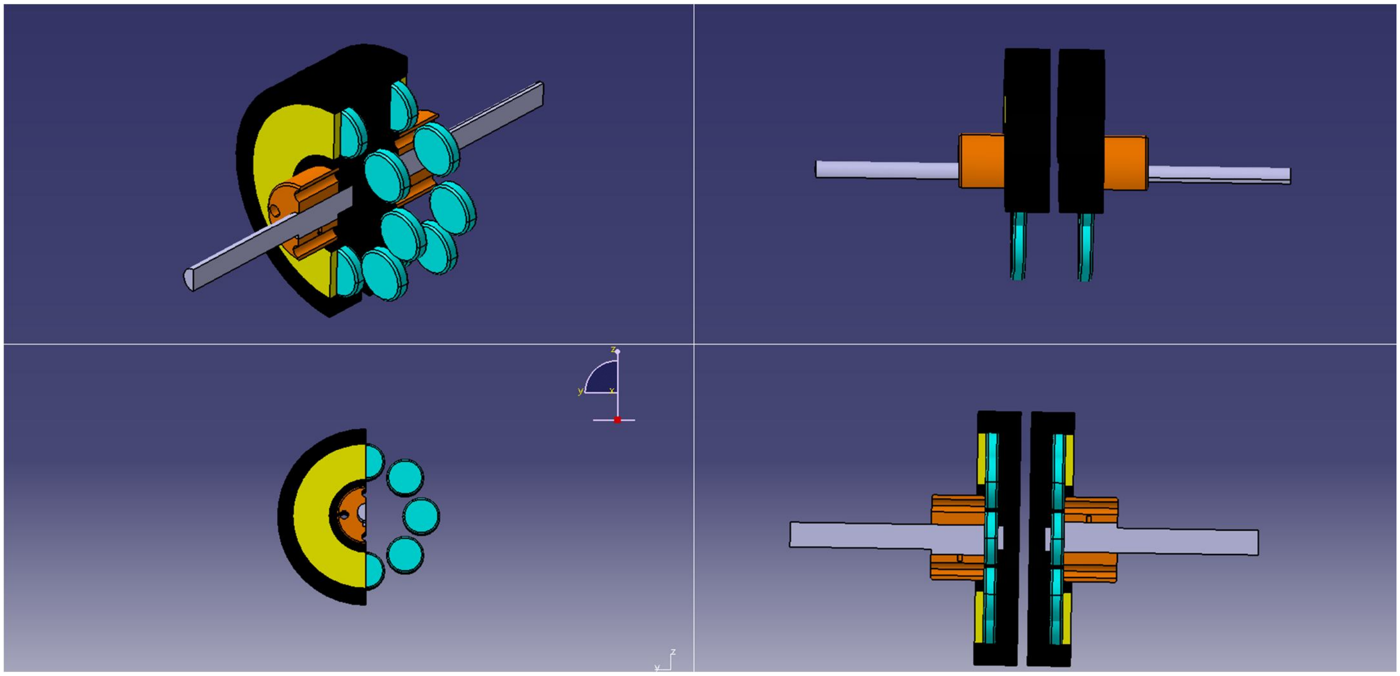

Fig. 4: CAD model of magnetic coupling

IV. CONCLUSION

The mathematical model is used for theoretical analysis of coupling to find the torque transmitted by coupling for the given rpm and power input. Torque transmitting capacity of the coupling is affected by number of factors like number of poles, distance of magnets from centre of plates and air gap between the two magnets. With the help of obtained graph, as increase in air gap distance between two magnets, torque transmitting capacity decreases in exponentially. As the pitch circle radius of disc magnets from centre of brass plate increases, torque transmitting capacity of the coupling increases linearly. As the number of magnets of the magnetic coupling increases the torque transmitting capacity also increases.

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