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Design and Fabrication of Magnetic Drive System

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Abstract— A drive system is used to transmit the power from input to the output shaft. The contact between the meshing components will lead to loss of energy due to the friction between them. This paper aims at the design and fabrication of a magnetic friction-less drive system aiming at increasing the efficiency of the drive by minimizing the friction. Presently the system is designed for low speeds. However, theoretical implementation of this in high speed applications is suggested in this paper.

Keywords: **Contactless, Frictionless, Magnetic, Drive System.**

I. INTRODUCTION

A Drive System is a part of an Engine or a Mechanical device which brings about its dynamic movement. Mechanical, electrical, pneumatic and hydraulic drive systems are some of the drive systems currently in use. Gears, geared machines, electrical motors, pneumatic and hydraulic pumps are widely used in a broad spectrum of industry, where the rotational speed of an input source must be matched to the required rotational speed of an output load. Mechanical gears are often employed for this purpose but they are subject to wear, can overheat, are often damaged in an over-torque situation and require periodic lubrication and maintenance. All these drive systems encounter losses due to frictional contact between transmitting parts. The drive may be used to achieve a speed increase or decrease. A magnetic gear (MG) is a novel alternative gear system that can potentially replace the traditional gear systems with exaggerated working capacities. A MG offers a contactless transmission mechanism for speed and torque manipulation. MGs do not demand lubrication and also provide inherent overload protection. They have the potential to be the most efficient transmission system. Novel MG designs produce high torque densities, which are comparable with mechanical gears. The magnetic drive system envisaged in the paper consists of intermeshed gears which works on the principle of like pole magnetic repulsion. The proposed drive system is designed for the torque conditions of a bicycle. The drive system can be used for automobile drives and also for certain industrial applications considering the conditions and designs mentioned in the paper. The torque transmission abilities of drive systems for different types of magnets are also compared in the paper.

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II. LITERATURE SURVEY

The design of a magnetic drive system incorporates magnetic bevel gear type of gearing. Using the magnetic property in mechanical systems to transmit motion was introduced as early as 1900AD. The first magnetic gear can be traced back to 1901 when C.G. Armstrong designed an electromagnetic spur gear [8]. The fundamental operating principle of the magnetic gear is very similar to that of conventional mechanical gears except that the force/torque transmission exerted by tooth meshing is replaced with the contactless magnetic interaction. Early magnetic gear development primarily focused on spur type. H. T. Faus patented a simple design of magnetic gears in 1941 which resembled the spur gears [7]. Though the drive did not prove as efficient as mechanical gears, it was capable of transmitting the rotational motion between two magnetic gears. For these Magnetic Gear topologies, their torque densities simply cannot compete with that of their mechanical counterparts. A noteworthy concept of a Magnetic Gear was introduced in the late 1960s, which features three concentric parts, i.e. an inner magnet rotor, an outer magnet rotor and a flux modulator between them. Further study on this new Magnetic Gear topology was done by N. Laing [5] and B. Ackermann [4]. There are many magnetic gearing arrangements that could be considered for designing of a magnetic drive system. Some of the gear types considered from “Magnetic Gear Technologies: A Review” by TM Tlali et & al., [1]. Among the magnetic gear topologies, the magnetic bevel gear is the type of gearing suitable for perpendicular power transmission over a long distance. The drive suits for transmission of power in cycles, automobiles as well as for the industrial purposes. Yao et al., have proposed a magnetic gear system where the torque analysis has been made. In this approach, the torque achieved is in the range of 2.8N-m – 5.8N-m which is considered to be low. Ramsden et & al, have used the FEA based analysis when an outer rotor directs the drive permanent magnet generator. In this approach, the mechanical deformation of the machine happens even in the case of time harmonic magnetic fields. Ando et & al., have developed a cylindrical magnetic gear with 1:2 gear ratio.

Krishna K Uppalati [3] suggests that by replacing the conventional drive system with the magnetic drive system would increase the transmission efficiency up to 99.44%. The author also suggested that the magnetic drive system could also produce torques up to 30N-m. These types of magnetic gears are concentric magnetic gears having flux modulators between the concentric magnets. Considering the above statistics G. Muruganandam et & al., [2] tried design and analysis of magnetic gears which would constructionally resemble the conventional gears. The results were phenomenal as they suggested the torque up to 6Nm might be achieved by magnetic spur gears. Further G. Muruganandam et & al., analyzed the magnetic bevel gear to find the torque developed to be 30Nm. Thus, it shows that magnetic bevel gear is more effective as a bevel gear than a spur gear. Considering the novel magnetic gear proposed by G. Muruganandam et & al., the magnetic drive system has been designed for perpendicular power transmission over a distance. The drive can be incorporated in bicycle, automotive and also in few industrial drives.

III. STATEMENT OF THE PROBLEM

In a conventional drive system, the contact between working components will negatively affect the drive system efficiency. A major part of power developed is lost due to friction between meshing drive components. This paves the need for a drive system in which the frictional losses are zero or minimal. The magnetic drive system seems promising in solving the above-mentioned problems.

IV. OBJECTIVE

➢ To design a magnetic drive system which will withstand the same external conditions as that of a conventional drive system.

➢ To fabricate and experimentally verify the magnetic drive system and to compare it's working with the conventional drive systems.

V. METHODOLOGY

A. *Source of identification of problem:*

➢ The major part of the power developed by an engine or a prime mover is lost due to friction between transmission components.

➢ It has been seen from the research that the maximum efficiency of a conventional drive is 80%-85% [3].

B. *Requirement survey:*

➢ A non-conventional drive system that could eliminate the friction and is capable of transmitting power equivalent of its mechanical counter-part is the need of the hour.

➢ Using magnetic gears for power transmission promises to solve this problem and can potentially replace mechanical drive in future years.

➢ The most commonly available permanent magnets are Ferrite magnet giving magnetic field up to about 0.34T is used for the model.

C. *Principle and construction:*

➢ The basic working principle is that the like poles repel and the unlike poles attract each other.

➢ The drive system functions similar to a torque tube driven drive system but consists of magnetic bevel gears instead of conventional gears.

➢ The power is transmitted between two shafts which are parallel to each other separated by a distance of 450mm.

➢ The meshing of the torque tube with wheels resembles meshing of bevel gears.

D. *Fabrication and testing:*

The design is converted into a model with the help of engineering drawings and the results have been verified experimentally. The comparison with the conventional drive system is done. Also, the comparison of magnetic drives using ferrite magnets and neodymium magnets is done and the under mentioned conclusion is drawn.

VI. PRINCILE PARTS

A. *Frame:*

The frame is the base component on which all the drive mountings are made. It is made up of mild steel for providing the supporting structures for the wheel magnet holder, for mounting the shaft as well as for the torque tube.

B. *Wheel magnet holder:*

Wheel magnet holder is a 3D printed component made up of ABS (Acrylonitrile Butadiene Styrene). It has a honeycomb structure in order to reduce the weight and to increase the structural rigidity of the 3D printed part. It has a flattened frustum structure consisting of slots on its slant faces for holding magnets. The slots on the slant faces are designed in a manner that increases the magnetic flux when the torque tube magnet holder is placed closer to it. The wheel magnetic holder consists of 24 slant faces to maintain the gear ratio of 1:4 with the 6 faces of torque tube magnet holder.

C. *Torque tube magnet holder:*

Torque tube magnet holder is also a 3D printed component made up of ABS (Acrylonitrile Butadiene Styrene) which has a honey comb structure in it for enhancing the rigidity and weighs lesser than the total fill mould. It is a frustum cone structure consisting of slots in the slant faces for holding magnets. The torque tube magnet holder consists of 6 slant faces to maintain a gear ratio of 1:4 with the 24 faces of wheel magnet holder. It is attached to the torque tube where the motion is transmitted.

D. *Torque tube and shafts:*

The two, wheel magnet holders and two torque tube holders are mounted on shafts. The shafts are supported by Plummer blocks. The torque tube is made of aluminum in order to reduce the effect of magnetic forces on the tube.

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The aluminum shafts holding the wheel magnet holder are 35mm in diameter. The torque tube is also aluminum shaft of 30mm diameter. The torque tube holds magnet holders on either end.

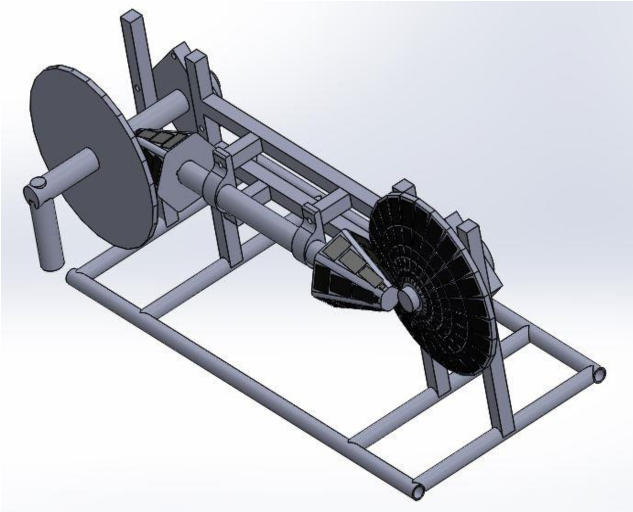

Figure i. Isometric view of magnetic drive system

VII. WORKING

The basic working principle is that the *like* poles repel and the *unlike* poles attract each other. The bond formed between the spatially separated magnetic bodies through a magnetic field will affect the orientation of the magnetic field. If an atom has a nonzero magnetic moment, an external field will tend to orient it along its own direction. A positive moment between them that is parallel to the field, called the paramagnetic moment, arises as a result. The Coulomb law states that the force of attraction or repulsion between two magnetic poles is directly proportional to the product of the strength of the poles and it is inversely proportional to the distance between them squared. The drive system functions similar to a torque tube driven drive system but consist of magnetic bevel gears instead of conventional gears. The power is transmitted between two shafts which are parallel to each other separated by a distance of 450mm. The wheel magnets holder along with the magnets are mounted on the two shafts and a torque tube with magnet holders on either side is placed in such a way that the magnets meshes the magnets of the wheel holders or in other words the magnetic fields due to magnets on the torque tube magnet holder interacts with that of the wheel magnet holder. This meshing of the torque tube with wheels resembles meshing of bevel gears. The magnetic faces on wheel and torque tube holders are maintained to be 24 and 6 respectively in order to obtain torque multiplication of 1:4. In working, as and when the one of the wheels is rotated by using the pedal mounted on the shaft adjoining to the wheel, the magnetic field of the magnets present on the wheels interact with the magnetic fields of the magnets present on the torque tube magnet holder. Due to the repulsion of like poles and attraction of unlike poles the torque tube is rotated. The same interaction takes place at the other end of the torque tube resulting in rotation of the wheel, thus effectively transmitting power across two parallel shafts. The amount of torque that can be transmitted depends on the air gap between the magnets on the wheel and the torque tube. The lower the air gap, higher is the torque transmitted. Moreover, the amount of torque transmitted also depends on the type of magnet used for the drive. Using Neodymium magnets increases the torque transmission capacity due to powerful magnetic strength of the Neodymium magnets.

VIII. CALCULATION

The magnetic drive system consists of two magnet wheels and a torque tube consisting magnet holder on either end. The specification as shown below:

TABLE I. PARAMETERS

DESCRIPTION	MAGNETIC BEVEL GEAR
Pair pole configuration	N_w=24; N_t=6
Radius of low speed rotor	Bottom = 240mm & Top = 40mm
Radius of high speed rotor	Bottom = 90mm & Top = 30mm
Air gap length (lg)	2mm
Permanent magnet material	Ferrite
Permeability of air region μ0	$4\pi\times10^{-7}$

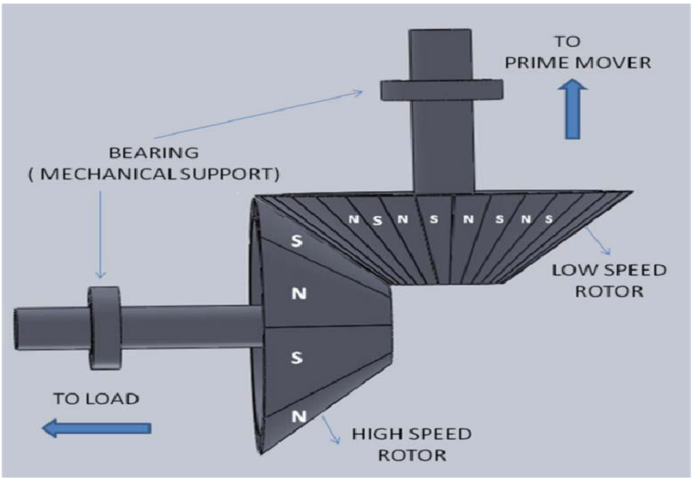

Figure ii. Working of magnetic bevel gear

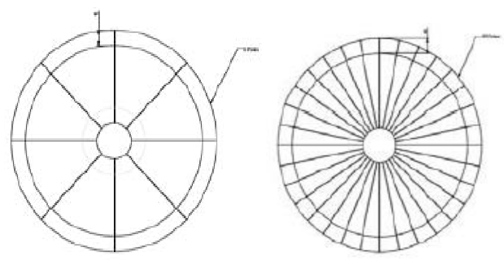

Figure iii. Magnetic bevel gear design

According to the principle of transformation of magnetic energy to mechanical energy, the following equation are obtained.

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$$T = \frac{1}{2\omega\mu 0} \oint B^2 dV$$

(Equation 1)

Where, T – Torque in Nm.

μ0 – Permeability of free space.

B – Magnetic field in T.

ω – Angular velocity in rpm.

dV – Change in volume between two meshing surfaces.

On substituting B=0.31 T and ω= 15 rpm.

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T = 1.007 Nm

For Neodymium Magnets N52, B=1.4T. The torque values for N52 are shown in the analysis section.

IX. RESULTS

Testing was carried out to verify the analytical results of the magnetic drive system. To test the Force generated by the system and to calculate the torque output of the system, a balsa wood rod of 450mm length was fixed to one of the magnetic wheel plates. The input was given and the output was measured by using a Digital Weighing Scale and the output values (the values of load on the digital scale) were noted.

Figure iv. Testing and result

Table ii. Comparison table of ferrite & neodymium magnets i

Sl No.	Magnet	B (tesla)	Torque (Nm)
1	Ferrite	0.31	0.909
2	Neodymium	1.4	20.54

As seen from the above table, the experimental torque measured is 0.909Nm in comparison with theoretical torque of 1.007N-m at 15rpm.

Efficiency, η = **Error! Reference source not found.** (Equation 2)

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η = 90.26%

For this project, the area of the magnet filled is 60%. If the whole magnetic wheel is made with magnetic material, the torque will be as follows:

Table iii. Comparison table of ferrite and neodymium magnets ii

Sl No.	Magnet	B (tesla)	Torque (Nm)
1	Ferrite	0.31	1.41
2	Neodymium	1.4	28.75

Hence from the above tables it can be concluded that the magnetic drive system of Ferrite magnet might be used as the drive in a bicycle and the Neodymium drive system might be used for high torque and low speed drives.

X. SCOPE OF THE PROJECT

➢ The magnetic drive system would prove to be the most efficient drive system.

➢ Since the availability of fossil fuels is reducing over the years, innovative, efficient non-conventional drive systems have a very good scope in the immediate future.

XI. CONCLUSION

➢ The designed frictionless drive system has verified to produce efficiency greater than that of the conventional drive system. The Conventional Drive Systems gives efficiency of 80-84% [3] whereas, the Magnetic Drive System gives efficiency of 90%.

➢ The Magnetic Drive System has all the potential to be used as a substitute for conventional drive systems but for low speed and high torque applications.

➢ The slippage at high speeds also acts as inherent overload protection.

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