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Design and Development of Magnetic Power Transmission System

Ajinath Bankar
UG Student,
Dept. of Mechanical Engineering,
S.B.Patil College of Engg. Indapur.

Amol Khamgal
UG Student,
Dept. of Mechanical Engineering,
S.B.Patil College of Engg. Indapur.

Sachin Shende
UG Student,
Dept. of Mechanical Engineering,
S.B.Patil College of Engg. Indapur.

Prof. Kolgiri S. G. (Ph.D)
Associate Professor
Dept. of Mechanical Engineering,
S.B.Patil College of Engg. Indapur.

Abstract:

A magnetic coupling is a coupling that transfers torque from one shaft to another shaft, by using a magnetic field rather than a physical mechanical connection. Magnetic shaft couplings are most often used for liquid pumps and propeller systems, since a static, physical barrier can be placed between the two shafts to separate the fluid from the motor operating in air. Magnetic shaft couplings preclude the use of shaft seals, which eventually wear out and fail from the sliding of two surfaces against each another. Some diver propulsion vehicles and remotely operated underwater vehicles use magnetic coupling to transfer torque from the electric motor to the propeller.

Magnetic gearing is also being explored for use in utility scale wind turbines as a means of enhancing reliability. The magnetic coupling has several advantages over a traditional stuffing box.

Keywords: ***Magnetic coupling, permanent magnets, power transmission efficiency etc.***

INTRODUCTION:

The objective of these study is to replace mechanical gears which are noisy, require frequent maintenance and lubrication, and suffer from friction losses. The magnetic gear is contactless and quiet in operation, and it requires no lubrication. In addition, it slips when overloaded whereas the mechanical gear may break down when overloaded. The magnetic gear transmission is used for mechanical gear transmission with help of the magnet and electrical motor. This is transducer electrical energy convert to the mechanical energy. The ability to hermetically separate two areas when continuing to transmit mechanical power from one to the other makes these couplings ideal for applications where prevention of cross contamination is essential .For instance: hydraulic sectors, dosing systems, compressors, sterilizers, industrial ovens, biotechnology, subsea equipment, pharmaceutical industry, chemical industry, food industry, generators, mixers.

A magnetic coupler transmits a force without any actual physical contact. Since magnetic forces attract and repel, and this force performs work, the action can be linear or rotary. A simple magnetic coupler has a follower and a driver. The driver is connected to a motor, while the follower reacts to the driver's motion, and this results in the transmission of mechanical energy without contact. To understand a magnetic coupler, it is helpful to understand magnets. A magnet produces a magnetic field or force.

This force acts on ferromagnetic materials and pulls them together or pushes them apart. Ferromagnetic materials include iron, cobalt, nickel, and certain alloys.

The overall strength of a magnet is measured by what is termed its magnetic moment, or by the magnetic flux that is produced.

Principles of operation:

The magnetic coupling works by using the power generated by permanent magnets. No external power supply is needed. These are permanent magnets not electro magnets.

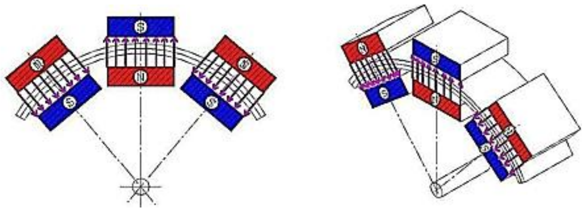

Figure: 1.1 Principles of operation of magnetic coupling

The magnets are installed alternating between poles in a side by side and opposing position as seen in the diagram. The main body of each coupling half is of ferromagnetic material to aid the channeling of the magnetic field correctly and therefore maximizing transmittable torque.

LITERATUREREVIEW:

Yi-Chang Wu et.al. Says in the paper "Transmitted Torque Analysis of a Magnetic Gear Mechanism with Rectangular Magnets" that Magnetic gears transmit torque by noncontact magnetic coupling rather than meshed mechanical gear teeth. In contrast to traditional mechanical gear mechanisms, non-contact magnetic gear mechanisms possess unique features of low mechanical energy loss, overload protection ability, no need for lubricants, and tolerance of misalignment and vibration isolation between adjacent mechanical parts. The analysis of transmitted torque is a prerequisite task when evaluating the performance of a magnetic gear mechanism. The two dimensional finite-element analysis (FEA) is further employed in computing the magnetic fields and transmitted torques of external-type magnetic gear sets. The results of this paper are beneficial for further design purposes and optimization of magnetic gear mechanisms.

Wang, Li says in the paper "Design and Construction of a Prototype Solenoid Coil for MICE Coupling Magnets" that a superconducting coupling solenoid mounted around four conventional RF cavities, which produces up to 2.6 T central magnetic field to keep the muons within the cavities, is to be used for the Muon Ionization Cooling Experiment (MICE). In order to validate the design method and develop the coil winding technique with inside-wound SC splices required for the coupling coil, a prototype coil made from the same conductor and with the same diameter and thickness but Only one-fourth long as the coupling coil was designed and fabricated by ICST. The prototype coil was designed to be charged to strain conditions that are equivalent or greater than would be encountered in the coupling coil. This paper presents detailed design of the prototype coil as well as developed coil winding skills. The analyses on stress in the coil assembly and quench process were carried out.

Jose Luis Perez-Diaz says in the paper "Contactless Mechanical Components: Gears, Torque Limiters and Bearings" that contactless mechanical components are mechanical sets for conversion of torque/speed, whose gears and moving parts do not touch each other, but rather they provide movement with magnets and magnetic materials that exert force from a certain distance. Magneto-mechanical transmission devices have several advantages over conventional mechanisms: no friction between rotatory elements (no power losses or heat generation by friction so increase of efficiency), no lubrication is needed (oil-free mechanisms and no lubrication auxiliary systems), reduced maintenance (no lubricant so no need of oil replacements), wider operational temperature ranges (no lubricant evaporation or freezing), overload protection.

Noboru Niguchi et.al. Says in the paper "Transmission Torque Characteristics in a Magnetic Gear" that the transmission torque characteristics in a surface permanent magnet-type (SPM-type magnetic gear. The operating principle of this gear and its transmission torque under the synchronous operation in accordance with the gear ratio are formulated. And the high order components contained in the cogging torque are verified by employing the 3-D finite element method (FEM) and carrying out measurements on a prototype. Furthermore, a method for reducing the cogging torque is discussed. The operating principle and transmission torque characteristics in a SPM-type magnetic gear was formulated, and verified by employing the 3-D FEM analysis and the experiment.

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SYSTEM ARCHITECTURE:

A magnetic gear uses permanent magnets to transmit torque between an input and output shaft without mechanical contact. Torque densities comparable with mechanical gears can be achieved with an efficiency up To 95% at full load and with much higher part load efficiencies than a mechanical gear. For higher power ratings a magnetic gear will be smaller, lighter and lower cost than a mechanical gear. Since there is no mechanical contact between the moving parts there is no wear and lubrication is not required. Magnetic gears inherently protect against overloads by harmlessly slipping if an overload torque is applied, and automatically and safely re-engaging when the fault torque is removed.

Magnomatics has developed a range of magnetic gear technologies for achieving low and high ratios and a linear gear variant. The magnetic gear concept has been extended to provide both an ultra-high torque density pseudo direct drive electrical machine and a variable ratio gear topology for continuously variable transmission systems.

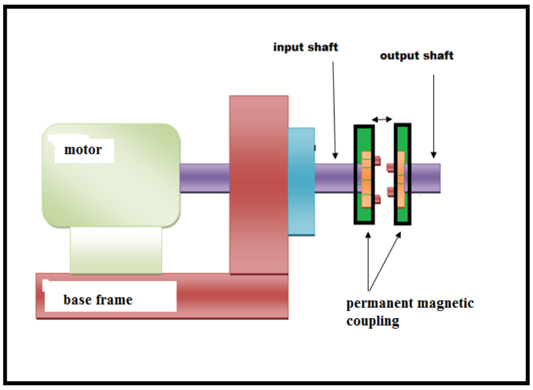

Figure: 3.1 schematic working of contactless magnetic power transmission system

CONTROL PARAMETERS OF THE SYSTEM

Following are the control parameters of the system

1. The prime mover of the system i.e. electric motor.
2. The strength of permanent magnets used in coupling.
3. The gap between the two connecting shafts i.e. space between couplings as it plays important role because of electromagnets strengths range.

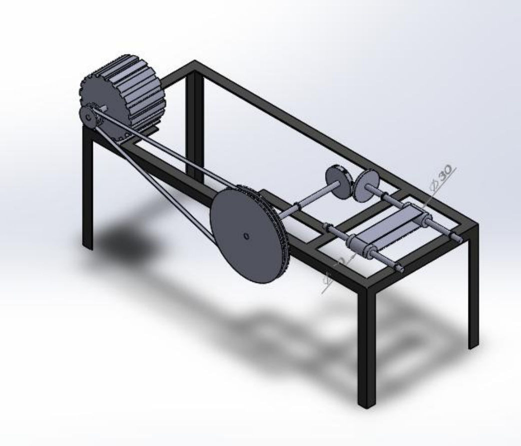

Fig. proposed model using CATIA V5 CR21

SYSTEM DESIGN:

Prime mover:

We select electric single phase AC motor as prime mover. Induction motors are the most used driving system, from fractional horsepower to hundreds of horsepower, where speed rotation does not require varying. Single-phase induction motors are largely used in low power applications. Thus bearing design strongly depends upon the final application of the motor. The types of fractional horsepower motors are:

MS series low voltage squirrel cage induction motor
Output Power = 15 watt
Shaft diameter = 15 mm
Voltage= 12 volt DC
Torque= 15 Kgcm= 1.47 Nm.
Speed= 100 rpm

Base frame design

WE design a basic frame for a prototype by mild steel channel (L beam), L Channel- MS Angles are L-shaped structural steel represented by dimension of sides & thickness. For e.g. 25x25x3 means, both the sides of angles are 25mm and thickness is of 3mm.

Shafts design

Input Power by AC motor = 12 watt.

SHAFT STRENGTH UNDER TORSIONAL LOAD

The shafts are always subjected to fatigue load hence they must be calculated for fatigue strength under

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combined bending and torsion loading. However, the initial estimate of diameter is obtained from the torque that is transmitted by the shaft. The bending moment variation along the length of the shaft is established after fixing some structural features like distance between supporting bearings and distance between points of application of forces and bearings. The power transmitted by shaft and the torque in the shaft are related as

$d3 = Mt*16 /\pi 10^{3}\ \tau$

Taking allowable shear stress for shafts under small loads in coupling as τ= 8 MPa = 8*106 Pa

$d3 = Mt*16 /\pi\ \tau\ 10^{6}$

$d3 = 1.47*16 /\pi*8*10^{6}$

$d3= 0.935 *10^{-6}$ m

d= 0.0097 m = 9.7 mm

Considering factor of safety as 1.5, the shaft size will be

D= 1.5*d

D= 1.5*9.7

D= 13.5 mm.

So selected shaft diameter closest to D= 13.5 mm is = D=15 mm. Which is taken as 15 mm to add better safety and availability in market. So we take diameter of second shaft will also be 15 mm.

BEARING SELECTION

Bearing are required to mount on the shaft to the frame stand. The use of bearings is to provide the end supports to the shafts as well as to provide a relative movable support. So that the pulley can rotate about its axis. We use here roller contact bearing of ball type.

The shaft diameter is 15 mm so requires bearing has to be 15 mm inside diameter. According to bearing designation, 6002 will be appropriate for this assembly. As it have 15 mm inside diameter to mount the pulley shaft. Here we have two pulleys giving us two shafts which has four ends, so quantity of bearings required is 4.

RADIAL BALL BEARING: 6202

DIMENSIONS OF BEARING:

Inside diameter= 15mm, outside diameter =35 mm, wide= 12 mm.

PULLEY BELT DRIVE

The belt drive is used here to transmit power from AC motor to the driving disc of coupling. The pulley is of V slot of angle β=25 0. Single Belt Transmission - one driving pulley and one driven pulley for a system with two shafts and two pulleys –

As indicated with pulley 1 and 2 in the figure above:

$$d1/d2 = n2/n1$$

$$d1\ n1= d2\ n2$$

Where,

d1 = driving pulley diameter (inch, mm)

n1 = revolutions of driving pulley (rpm - rounds per minute)

d2 = driven pulley diameter (inch, mm)= 230 mm

n2 = revolutions of driven pulley (rpm - rounds per minute)

The input power by motor is 12 watt and motor speed is 100 rpm.

The standard pulley attached to motor is of diameter 70 mm. So d1 = 70 mm

N2 = d1N1 / d2

N2 = 70*100 / 230

N2 = 30 rpm

Magnetic Coupling

Driving disc

The driving disc is made of up of Mild steel circular tube and circular plate welded to form a cup and on the circumference of this cup the permanent magnets are attached to form a magnetic coupling.

The shaft is welded to center of cup to circular plate of diameter 15 mm and length of 200 mm.

TORQUE AND POWER TRANSMITTING COMPARISON:

Power transmitted by belt drive

The input power by motor is 15 watt

To calculate power transmitted by belt drive,

This belt drive consists of one V-belt, on grooved pulleys of the size 230 mm and 30 mm. The angle of the groove is 25°. The cross-sectional area of each belt is 100 mm2 (i.e width b * t thickness = 10*10 = 100

mm2) and μ= 0.12. The density of the belt material is 1200 Kg/m3 and the maximum safe stress in the material is 0.3 MPa.
We have to calculate the power that can be transmitted between pulleys of 230 mm diameter rotating at 100 rpm.
We know that mass of the belt per meter length,
m = Area × length × density = 100 × 10-6× 1.081 × 1200 = 0.129 kg/m
And speed of the belt,
V= πdN/60 = 3.142 *0.230 *30/60 = 0.36 m/sec

Centrifugal tension:
Tc = m.v2 = 0.129 (0.36)2 = 0.0167 N
And maximum tension, T = σ× a = 0.3 × 106 × 125 × 10-6 = 37.5 N

We know that tension in the tight side of the belt,
T1 = T – TC = 37.5 – 0.0167 = 37.4833 N
Let T2 = Tension in the slack side of the belt.

Since the pulleys are of the same size, therefore angle of lap (ϴ) = 180° = π rad. We know that
2.3 log (T1/T2) = μ ϴcosecβ
2.3 log (T2/T1) =0.12*3.142*cosec12.5
So
T1/T2= 5.7187
T2= T1/5.7187 = 37.4833 / 5.71= 6.55 N

Power transmitted:
We know that power transmitted,
P = (T1 – T2) v = (37.4833 – 6.55) 6.02 = 11.13 Watt

Power transmitted by magnets in magnetic coupling

Magnets are an important part of our daily lives, serving as essential components in everything from electric motors, loudspeakers, computers, compact disc players, microwave ovens and the family car, to instrumentation, production equipment, and research. Their contribution is often overlooked because they are built into devices and are usually out of sight.

Force exerted by magnets in magnetic coupling,

Force is calculated by

F = 0.577 * B^2 *A*N
For Neodymium Iron Boron magnet
B= 175 kJ/m3
N= Number of magnets = 4
A= area for 30 mm round magnet= π/4 D2 = 7.06*10-4m2
F=0.577*1752*7.06*10-4*4
F=49.9 N

Torque transmitted:

Torque exerted by this magnetic force onto disc coupling is calculated by,
Torque = force*perpendicular distance
Torque = force*radius of disc
Disc diameter= 130 mm so radius will be R= 65 mm= 0.065 m
Torque T = F*R
T= 49.9*0.065
T= 3.24 Nm.
So the torque transmitted by the magnetic coupling is 3.24 Nm.

Power transmitted:

The power transmitted by the magnetic coupling is calculated by,
P= 2πNT/60 watt.
P= 2*3.142*30*3.24/60
P= 10.18 watt.

Transmission Efficiency of system

1. Transmission efficiency of mechanical contact system i.e. belt drive
   Transmission efficiency of the system is calculate by
   ηt = power transmitted by belt drive / input power from electric AC motor
   ηt = 11.13 / 15
   ηt = 0.76 = 74.20 %

2. Transmission efficiency of magnetic coupling
   Transmission efficiency of the system is calculate by,
   ηt = power transmitted by magnetic coupling / input power from belt drive

nt = 10.18 /11.13
=0.9604
nt= 91.46 %

So the transmission efficiency of this magnetic coupling is 91.46 % which is way better than contact mechanical coupling of joints and gears which is considered normally as 70-80 %.

Conveyor calculations

The basics of the Calculations of Conveyor Belt Design Parameters

Belt tension: The belt of the conveyor always experience a tensile load due to the rotation of the electric drive, weight of the conveyed materials, and due to the idlers. The belt tension at steady state can be calculated as:

Tb = 1.37*w*f*L*g
Where,
Tb is in Newton.
W= weight of object = 1 kg
f = Coefficient of friction usually 0.35
L = Conveyor length in meters. Conveyor length is approximately half of the total belt length.
L= 300 mm= 0.3 m
g = Acceleration due to gravity = 9.81 m/sec2
Tb = 1.37*w*f*L*g
Tb = 1.37*1*0.35*0.3*9.81= 1.41 N

Power at drive pulley: The power required at the drive pulley can be calculated from the belt tension value as below:

Pp = (Tb*V)/1000……………..eqn.1.2
Where,
Pp is in KW.
Tb = steady state belt tension in N.
v = max permitted belt speed in m/sec. = 2 m/sec.
Pp = Tb*v/1000= 1.41*2 /1000= 0.00282 KW
= 0.0282*1000 W
= 2.82 WATT. = 3 watt

POWER REQUIRED TO DRIVE
Pm = Pp/Kd
Where,
Pm= Power required by magnetic coupling to drive is in Watt

Pp = the power at drive pulley in = 3 WATT

Kd = Drive efficiency of belt drive = 85 %
SO
Pm = Pp / 0.85 = 3.52 WATT = 4 WATT.

Torque required to rotate belt drive
P= 2πNT/60

Considering output speed of magnetic coupling to be 250 rpm.
4=2*3.142*250*T/60
T= 0.1527 Nm

So the torque transmitted by the magnetic coupling is 0.4264 Nm.

Hence magnetic coupling is enough capable to drive belt drive. As 3.24>0.1527.

RESULTS:

The following results were obtained during testing the experimental setup of our system “magnetic power transmission system” with use of permanent magnets coupled Disc drive.

Our system successfully demonstrates the benefits of contactless power transmission like , higher transmission efficiency, reduced power loss, no friction as it is contactless and hence no wear of components and system so greater life of system. Above all there is no noise and vibrations like contact system.

The calculated numerical values during testing of the project are as follows,
1. Power transmitted by belt mechanism = 11.13 watt
2.Power transmitted by magnetic coupling = 10.18 watt
3. Torque transmitted by magnetic coupling = 3.24 Nm.
4. Transmission efficiency of mechanical contact system = 74.20 %

5. Transmission efficiency of mechanical contact system = 91.46 %

ADVANTAGES:

1 No physical contact hence no friction, wear or vibration.
2 Higher transmission efficiency.
3 Easy to maintenance.
4 Repairing is easy.
5 Low cost.

APPLICATIONS:

It has the ability to hermetically separate two areas whilst continuing to transmit mechanical power from one to the other makes these couplings ideal for applications where prevention of cross contamination is essential. For instance: Hydraulic sectors, food industry, generators, mixers, dosing systems, compressors, sterilizers, industrial ovens, biotechnology, subsea equipment, chemical industry, pharmaceutical industry etc.

CONCLUSION:

Our system successfully demonstrates the benefits of contactless power transmission like, higher transmission efficiency, reduced power loss, no friction as it is contactless and hence no wear of components and system so greater life of system. Above all there is no noise and vibrations like contact system.

Magnetic couplings, clutches and brakes are both safe, reliable and particularly economical to operate. They work without wear or contact, are virtually maintenance- free, operate with low bearing friction (concentric ring couplings) and, under conditions of normal use, have an almost unlimited working life. They are particularly useful when it is necessary to ensure a strict, physical separation between the drive and driven side.

A magnetic gear uses permanent magnets to transmit torque between an input and output shaft without mechanical contact. Torque densities comparable with mechanical gears can be achieved with an efficiency >99% at full load and with much higher part load efficiencies than a mechanical gear. For higher power ratings a magnetic gear will be smaller, lighter and lower cost than a mechanical gear. Since there is no mechanical contact between the moving parts there is no wear and lubrication is not required.

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