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Magnetic Gearing System

H. Vaidyanath
UG Student
Department of Mechanical Engineering
BMS College of Engineering, Bengaluru, Karnataka
raviadarsh015@gmail.com

Abstract*: With the advent of technology and science, researchers have shown interest and developed a new technology incorporating permanent magnets. This concept is applied in magnetic gearing to achieve low-speed high- torque direct-drive operation. The speed is altered by the use of gears and gearboxes. The magnetic meshing of gear overcomes the limitations of mechanical gearing system like vibrations, noise, and friction due to contact. The efficiency of 99% or greater can be achieved at full load conditions. The magnetic force of attraction aids in the magnetic meshing of the gear teeth. There is no physical contact of the gear teeth. By the use of such system, the wear and tear of the gears are reduced to a great extent. The heat generated in the gears while working is almost nil in this method. Unlike mechanical gearing system, the process of transmitting power is smooth and silent. Magnetic gearing system can be incorporated in automobiles for transmission of power to achieve higher efficiency. This kind of setup requires very minimal maintenance. Permanent magnets are used to produce the magnetic field which helps in the transmission of energy without contact. Ferrite magnets and high power rare earth neodymium magnets are used in making the gears.

Keywords: Torque; Magnetic Meshing; Efficiency; Transmission, Neodymium; Permanent Magnets.

INTRODUCTION

As we know, most of the automobiles use mechanical gearing system for the power transmission. This is because of the high efficiency achieved and the high torque density available in this setup. But the only drawback which led to the discovery of magnetic gears is the contact friction in the teeth of mechanical gears. In addition to friction, noise and heat generated in mechanical gears often led to gear failure.

Nowadays, energy conservation and the environment are the main aspects to be taken care of while designing a new product. Magnetic gears are Eco-friendly as they are non-contact gears which produce zero noise while working. This idea of non-contact transmission of power attracted the attention of researchers to study and develop more on this technology.

The idea of magnetic gears came up in the early years of the 20th century.

In 1941, Faus proposed a magnetic gear which had a similar topology to that of a mechanical spur gear. But due to poor torque density of the ferrite permanent magnet material, it was almost impossible to use it for industrial purposes. Until the high-performance Neodymium, iron boron permanent magnet material was introduced in the 1980's. The structure was similar to that of a spur gear except for the slots and the teeth of the gear were replace by N-poles and S-poles of permanent magnets respectively. It was still not used in the industry as the low torque density of the permanent magnet prevailed.

In 2001, Atallah and Dave Howe proposed the idea of coaxial magnetic gear. The working principle of these gears is based on magnetic field modulation produced by two permanent magnet rotors through the ferromagnetic pole pieces.

High torque density and improved performance were achieved in this method.

The main advantages of magnetic gears over mechanical gears are:

1) Reduced maintenance and high reliability.
2) Lubrication-free.
3) Very low acoustic noise and vibrations.
4) Non-contact frictionless transmission of power.
5) Higher efficiency .(99% or greater for part loads)
6) Peak torque transmission.
7) Slip between gears due to overload causes zero damage to the gears as there is no contact.

8) Reduces harmful drive-train vibrations to a large extent.
9) Lower cost and lighter when compared to a mechanical gear for similar applications.

CONSTRUCTION

Firstly, two gear blanks are taken. The gear blanks are made of light non- ferromagnetic material like Phenolic laminated sheets (Hylam sheets)
One of the gears is the driving gear and the other one is the driven gear.
The driving gear is connected to the motor through a shaft used for the power transmission.
The permanent magnets (neodymium) are placed on the circumference of the gear blanks in alternate poles with the help of an adhesive (epoxy resins, araldite etc.). Figure (1) shows the schematic representation of the magnetic gear.

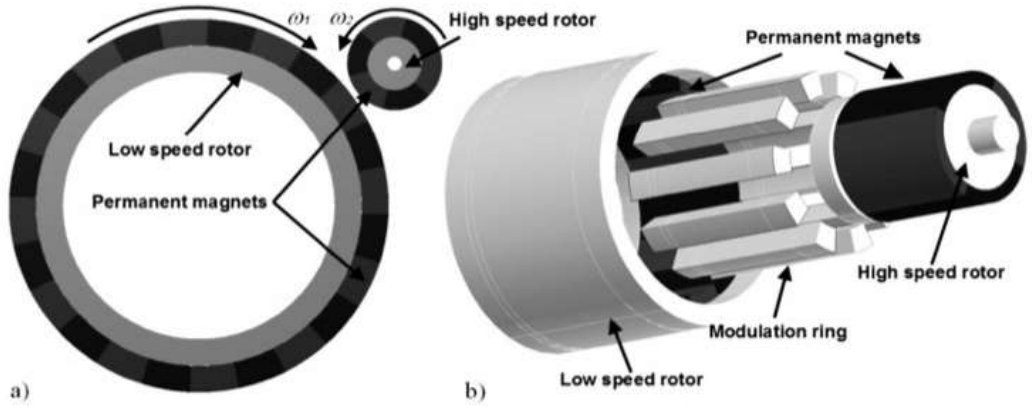

Figure (1). Schematic construction of magnetic gear

During working, the gears are placed close to each other but not in contact. The driven gear lies inside of the magnetic field of the driving gear. The speed and the gear ratio can be altered by increasing or decreasing the number of magnets on the gear blank circumference or by changing the value of the diameter of the gear blank.

OPERATING PRINCIPLE

The operating principle of magnetic gears proposed by Atallah and Howe in 2001 is analogous to that of an epicyclic gear assembly (planetary gear train assembly) where the inner rotor acts as the sun gear , the outer rotor acts as the annular gear (internal gear) and the stationary steel pole pieces (modulation rings) act as the planetary gears .

Hence, for the torque transmission in a magnetic gear train assembly, one of the afore-mentioned components must be at rest (locked) with respect to the other components. While designing, the element to be locked and the element to be driven must be mentioned. With each and every possible combination in the configuration of the assembly, there will be a change in the final drive ratio value. The configuration can be altered by changing the number of magnets in the inner rotor or outer rotor or by changing the number of ferromagnetic pole pieces for a given gear drive.
Whereas, magnetic gears basically work on the principle of transfer of magnetic flux through the air (without contact) from one gear to the other when both the gears are placed close to each other .(driven gear is placed in the magnetic field of the driving gear).

FORMULAE

The below formula [1] is used to determine the number of magnetic pole pairs of the annular gear (outer rotor) and the number of pole pieces in the modulation ring when the number of pole pairs in the sun gear (inner rotor) is known.

$$P_o = P_m - P_i \qquad [1]$$

Where,

P_o –- number of magnetic pole pairs in the annular gear (outer rotor).
P_m --- the number of magnetic pole pairs in the modulation ring.
P_i --- the number of magnetic pole pairs in the sun gear (inner rotor).

Case (i): When the modulation ring is locked and the inner rotor is driven by the motor.

The gear ratio (i_r) is given by

$$i_r = \frac{P_m - P_i}{P_i} = \frac{P_o}{P_i} \qquad [2]$$

In this case, the annular gear will rotate in the opposite direction to that of the sun gear.

Case (ii): When the annular (outer rotor) is locked and the sun gear (inner rotor) is driven by the motor.

The gear ratio (i_r) is given by

$$i_r = \frac{P_m}{P_i} \qquad [3]$$

In this case, the intermediate ring (modulation ring) and the sun gear (inner rotor) rotate in the same direction.

Generally, in this type of configuration setup, the inner rotor rotates at a higher speed compared to that of the outer rotor. Hence, the inner rotor is also known as the high-speed rotor and the outer rotor is known as the low-speed rotor.

TYPES OF MAGNETIC GEARS

Similar to that of mechanical gears, magnetic gears are categorized as

1. On the basis of the magnetic field.

I) Magnetic gears with direct effect.
II) Magnetic gears with the variable magnetic field. (Field modulated magnetic gears).

2. On the basis of configuration

I) Magnetic spur gear.
II) Magnetic bevel gear.
III) Magnetic worm gear.
IV) Magnetic rack and pinion gear.
V) Magnetic helical gear. Etc.

- Magnetic gears with direct effect :

The working principle of this type of gears is that the distance between the gears (driving and driven gears) is very short. Hence, the magnetic flux travels through the air medium between the two gears. Hyperboloid gear train assembly, epicyclic gear train assembly, and cycloidal gear train assembly work under this principle.

- Field modulated magnetic gears :

Unlike magnetic gears with direct effect, infield modulated gears (variable field), there is a component made of iron through which the magnetic flux passes from one gear to the other. The principle of work is mainly based on the use of ferromagnetic materials in between the rotors for magnetic field modification. These gears consist mainly of two rotors and a modulator.

- Concentric magnetic gear (planetary, linear), axial magnetic gear and co-axial magnetic gear work under this principle.

Magnetic gears based on configuration:

Magnetic spur gears, helical gears, bevel gears, worm gears, rack and pinion gears are very much similar to their counterpart in the mechanical system, both in construction and applications. Except for the working principle, efficiency and construction, all other design aspects are alike to that of in the mechanical system.

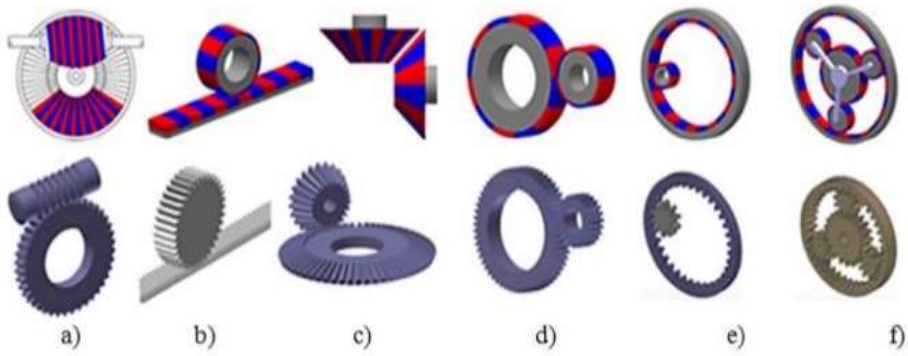

Figure (2): Comparative display between magnetic and mechanical gears.
a) Worm gear; b) Rack and pinion gear; c) Bevel gear
1. External spur gear; e) internal spur gear ;
f) Planetary gear train assembly.

APPLICATIONS OF MAGNETIC GEARS

1) Aerospace.
- Maintenance is reduced.
- Vibrations are isolated.
- Temperature range is large.

2) Applications in the field of robotics.
3) Magnetic gears are used in Automotive Regenerative Braking Systems.
4) Non – contact gearing for drilling motors, turbine generators.
5) Magnetic transmission in spacecraft is the latest take on this technology.

CONCLUSION

Environmental pollution is a global problem prevailing in our planet since the introduction of automobiles. The aim is to find solutions to reduce or resolve the effect. In this way, magnetic gears showcase their significance and importance to the environment. The use of magnetic gears in vehicles will prove advantageous as they pull down the amount of pollution from vehicles drastically.

The rate of depletion of fossil fuels in the past century has been rapid as the demand for these oils has been excessive and unreasonable.

Hence, magnetic gears is a major setback for this issue as the fuel consumption is minimal when it is incorporated with flywheels. Considering these qualities, it can be assumed that, in the near future, the use of magnetic gears will expand and we can hope to see automobiles using this technology for transportation. An elevation in quality of life and the environment can be examined if this technology is applied to good use**.**

SUMMARY

This paper describes the design and operations of magnetic gears. The advantages of magnetic gears over mechanical gears have been discussed. Significant features, types, constructions, and applications of different types of magnetic gears have been listed out. The potential of magnetic gears to replace mechanical gears, the reliability, availability and the complexity of the gears have been examined.

Scope for the future sustainability of natural resources is commendable. Environmental hazards and pollutants can be eliminated by a considerable fraction.

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