HIGH PERFORMANCE TORQUE OPTIMIZATION IN PERMANENT MAGNETIC GEAR FOR COMMERCIAL AND INDUSTRIAL USE

K. Manoj Kumar[1],
Department of Aeronautical Engineering
Hindusthan College of Engineering and Technology
Coimbatore -641032, India.

P.N. Karthikeyan[2],
Department of Aeronautical Engineering
Hindusthan College of Engineering and Technology
Coimbatore -641032, India.

S. Bhagavathi[3],
Department of Aeronautical Engineering
Hindusthan College of Engineering and Technology
Coimbatore -641032, India.

V. Godwin[4],
Department of Aeronautical Engineering
Hindusthan College of Engineering and Technology
Coimbatore -641032, India.

K. Jaivignesh[5],
Department of Aeronautical Engineering
Hindusthan College of Engineering and Technology
Coimbatore-641032, India.

S. Vetrival[6],
Department of Aeronautical Engineering
Hindusthan College of Engineering and Technology
Coimbatore -641032, India.

Abstract: *The main goal of the project is to substitute mechanical gear systems with magnetic gear systems. A mechanical gear system could lead to a lot of issues such as wear, and tear, mechanical loss, vibration, constant lubrication, and a lot of maintenance. The magnetic gear will function based on the principle of the magnetic attraction and repulsion method. The magnetic gear will generate torque with the magnetic coupling method. In this approach, the gear will be rotated by the magnetic field generated by permanent magnets. The magnet will be attracted and repelled in order to provide a rotational motion in gear. The principal aim of the research is to enhance the torque and regulate the speed of the magnetic gears.This study will assist in substituting the mechanical gears in turboshaft airplanes (gear box), propeller aircraft (reduction gearbox), and other commercial and industrial to enhance their performance.*

Keyword: **Magnetic gear, Mechanical gear, Gear box, Magnet, repulsion.**

1. Introduction

Magnetic gears or magnetic transmissions, magnetically linked gears, gear systems that utilize magnetic forces to transmit rotational motion and power. Magnetic gears take advantage of the interaction of magnetic fields for motion transfer with no physical contact between gears required. A magnetic gear is a device that transfers torque between two shafts utilizing magnetic fields rather than contact. Unlike conventional gears, which are meshed with one another by teeth, magnetic gears use permanent magnets in predetermined configurations to interact with each other through magnetic forces. This leads to contactless transmission of torque, minimizing wear, eliminating lubrication requirements, and enabling operation in sealed or hostile environments[3][4]. Magnetic gears have extensive usage in applications where low maintenance requirements, noise reduction, and input and output shaft isolation are required, including medical equipment, electric vehicles, and aerospace technology[2][5]. Magnetic gears can also be shaped to provide high gear ratios, overloading protection, and vibration damping, and therefore represent a highly versatile solution in high-end engineering applications.

MAGNETIC GEAR

Magnetic gears are one of the types of transmission elements that transfer torque from two rotating components through magnetic fields without direct physical contact, as is the case with conventional gears. The technology has ushered in new avenues of application in low-maintenance industries with high energy transfer efficiency and increased reliability. In contrast to mechanical gears, which are based on tooth meshing interaction, magnetic gears are based on magnetic fields interaction to provide torque transfer and have a number of distinct advantages. Magnetic forces transfer torque from input to output shafts without contact in magnetic gears with high efficiency and less wear. Contactless operations reduce friction, resulting in quieter operation and less maintenance. Their small size allows for their inclusion in a broad range of applications, such as in robotics, electric vehicles, and renewable energy systems[4][6][7]. Magnetic gears can handle high torques with the ability to remain functional for harsh applications. Magnetic gears are also beneficial in that they provide design flexibility such that design configuration can be customized to order according to specific needs. In conclusion, magnetic gears are high technology with high performance but low cost of operation and complexity.

TYPES OF MAGNETIC GEARS

There are different types of magnetic gears, each with its own set of applications. The most general types are: Coaxial Magnetic Gears: These include inner and outer rotors that are coaxial, i.e., have the same axis of rotation. The rotors have a series of permanent, alternately polarized magnets. It takes advantage of the interaction between inner and outer magnetic fields to deliver torque from the one to the other.

This is highly effective and often utilized in high-torque, low-speed applications.

- Linear Magnetic Gears: Unlike coaxial magnetic gears, linear magnetic gears convert torque into linear motion and not rotation. Linear magnetic gears are used in systems with linear motion needs, e.g., linear actuators or rail transportation[9].
- Planetary Magnetic Gears: Here, the magnetic gear is a B 665Ymechanical planetary gear set made up of a central sun gear (rotor), a planet gear set (magnets), and an outer ring gear. The arrangement has high torque density and finds application in cases where compactness and high torque are necessary[11].
- Axial magnetic gear: This type of gear possesses typically a magnetic interaction of magnets on two or more axes. Technology is on the two magnetic gear wheels with magnets on faces[4]. These interacting magnets generate a driving force on drive magnet wheel. All types of magnetic gear have certain advantages depending on the application, torque requirements, and design factors[10] .

AXIAL MAGNETIC GEARS

Axial magnetic gear is a machine which can transmit the torque from the shaft to a different shaft without contacting them using the magnetic field coupling mechanism. Here in this mechanism the two discs will be placed with magnets it assists in repelling and attracting the magnets towards each other to produce the moment of rotation and produce torque. This axial magnetic gearbox has several pieces of hardware like Input rotor, Output rotor, Modulator.

INPUT ROTOR

The input rotor is equipped with magnets according to the power. These magnets are placed in varied pole pieces the speed and torque depend one number of pole pieces are constant[4].

OUTPUT ROTOR

The magnets of this rotor act on the input rotor magnets. It is coupled with the driven shaft and turns according to the magnetic field of the input shaft[10]. The gear speed will be increased when the input is low combination and higher combination high torque will be generated.

MODULATOR

This modulator is located between the two rotors for magnetic interaction, and it affects the gear ratio[12][5]. Ferromagnetic materials are employed to use as a modulator since it will interact between magnetic fields and magnets. It prevents the air gap from closing up between the rotors.

2. Design Parameters

The table presents the complete specifications of the chosen magnetic gear and their scaled-down versions to provide more accurate results in the design and analysis stages. The comprehensive comparison helps to improve the AXIAL MAGNETIC GEAR concept for maximum performance and viability.

The table presents the cruising parameters of the chosen magnetic gear. offering vital information like radius and magnets dimensions. This data is important in optimizing the axial magnetic gear design to suit the gear performance.

Table 1. Design Parameters

DETAILS	PARAMETERS
Inner radius, drive magnets (mm)	40
Outer radius of the acrylic discs, drive magnets (mm)	70
Inner radius, source magnets (mm)	40
Outer radius, source magnets (mm)	70
Length of air gap (mm)	0.5-0.25
Magnets thickness (mm)	3
Magnets height (mm)	5
Magnet length (mm)	20
Number of pole pairs (source magnets)	16
Number of pole pairs (drive magnets)	16
Remanence of the permanent magnets (mT)	1.32
Direction of magnetization	AXIAL

- The axial magnetic gear system features coaxially aligned source and drive magnets, each ranging from an inner radius of 40 mm to an outer radius of 70 mm.
- The magnets are axially magnetized, i.e., the magnetic flux travels in the direction of the rotation axis, ideal for axial flux interaction.
- Both source and drive magnet sets consist of 16 pole pairs, resulting in the 1:1 gear ratio where synchronized torque transmission is possible.

- All the magnets measure 3 mm in thickness, 5 mm radial in height, and 20 mm tangential in length, specifying physical dimensions and location on the disc.
- The permanent magnets utilized have a remanence of 1.32 Tesla, which is standard for high-strength neodymium magnets, to provide effective magnetic coupling[7][9].
- The gap between drive and source magnets is between 0.25 mm and 0.5 mm, which is very important in maximizing torque density and coupling efficiency.

Acrylic discs are employed for mounting the magnets, and this makes the setup highly suitable for experimental testing and compact and precise torque transmission applications.

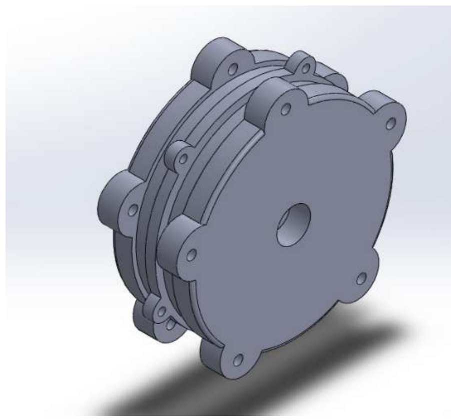


Fig 1. Finalized Design

ANSYS MAXWELL

- ANSYS Maxwell is software for simulation of electromagnetic system design and analysis.
- It is predominantly used for electric machines, transformers, sensors, actuators, and other electromagnetic devices.
- It supports simulation of 2D and 3D electromagnetic fields.
- It provides magnetic flux analysis, field distributions, induced currents, torque, force, and losses.
- ANSYS Maxwell enhances design performance, reduces prototyping cost, and shortens development time.
- It is extremely efficient for electrical and electromechanical design applications.

ANALYSIS PROCESS

Magnetic Field and Flux Density Calculation: From ANSYS Maxwell, the magnetic field strength and flux density are calculated to determine the electromagnetic characteristic of the system that is responsible for torque production in the axial magnetic gear.

Transition with Motion for Torque Calculation: To accurately calculate torque in an axial magnetic gear, a transition with motion should be utilized since it takes into account dynamic interactions between magnets while in operation. Limitations in ANSYS Maxwell Student Version: Because the student version of ANSYS Maxwell has restricted access, a full and thorough analysis, including motion-based transitions and torque calculation, cannot be effectively performed.

ANALYSIS TESTING

Magnetic flux lines to see how the magnetic field interacts within the gear Torque vs. speed characteristics. Magnetic force acting on different components of the gear EDDY CURRENT and losses(if using a transient or eddy current analysis)[14][16].

VALIDATION:

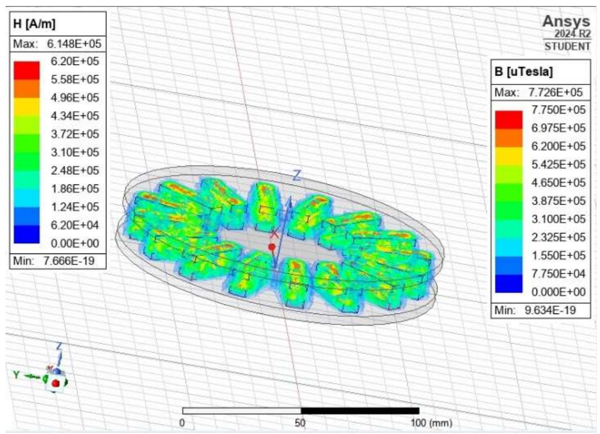


Fig 2. Magnetic flux density and field strength for 0.6 air gap

The 3D simulation output of ANSYS Maxwell 2024 R2 Student, which displays magnetic field intensity (H, in A/m) and magnetic flux density (B, in µT) distribution in an axial magnetic gear. Colour contours indicate the value of H and B, ranging from 1.825×10^4 A/m to 5.975×10^5 A/m for H, and from 2.293×10^4 µT to 7.508×10^5 µT for B. Maximum intensity occurs at the air gap and rotor poles. Arrows indicate the direction of magnetic flux, allowing for improvement in performance**.**

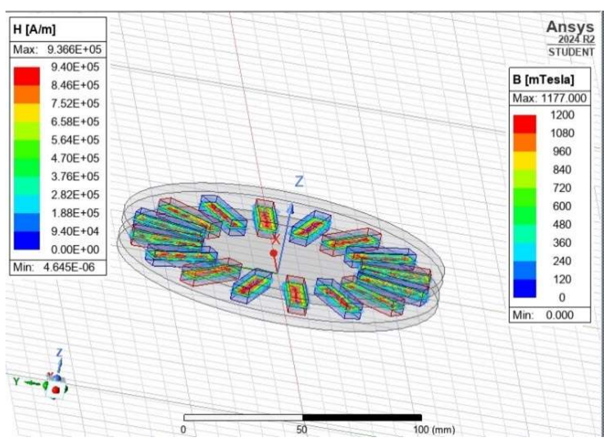


Fig 3. Magnetic flux density and field strength for 0.2 air gap

The 3D simulation output of ANSYS Maxwell 2024 R2 Student, which displays magnetic field intensity (H, in A/m) and magnetic flux density (B, in µT) distribution in an axial magnetic gear. Colour contours indicate the value of H and B, ranging from 1.88×10^4 A/m to 9.40×10^5 A/m for H, and from 120 µT to 1200 µT for B. Maximum intensity occurs at the air gap and rotor poles. Arrows indicate the direction of magnetic flux, allowing for improvement in performance.

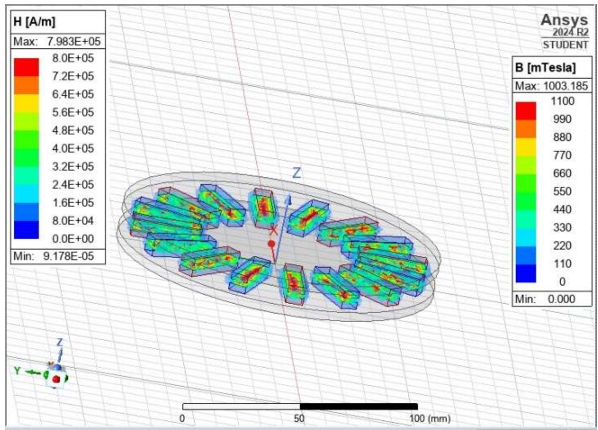


Fig 4. Magnetic flux density and field strength for 0.3 air gap

The 3D simulation output of ANSYS Maxwell 2024 R2 Student, which displays magnetic field intensity (H, in A/m) and magnetic flux density (B, in µT) distribution in an axial magnetic gear. Colour contours indicate the value of H and B, ranging from $8{\times}10^4$ A/m to $8{\times}10^5$ A/m for H, and from 110 µT to 1100 µT for B. Maximum intensity occurs at the air gap and rotor poles. Arrows indicate the direction of magnetic flux, allowing for improvement in performance.

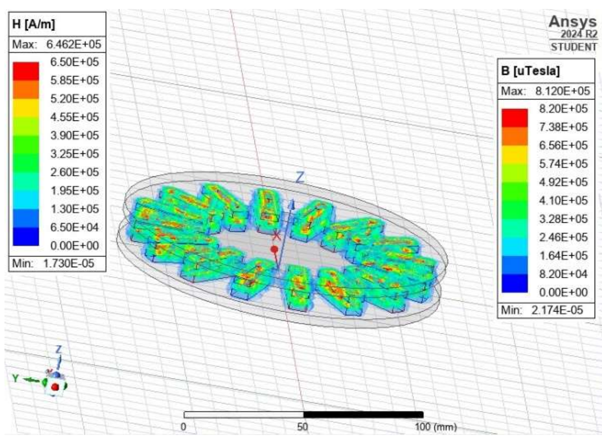


Fig 5. Magnetic flux density and field strength for 0.4 air gap

The 3D simulation output of ANSYS Maxwell 2024 R2 Student, which displays magnetic field intensity (H, in A/m) and magnetic flux density (B, in µT) distribution in an axial magnetic gear. Colour contours indicate the value of H and B, ranging from $6.50{\times}10^4$ A/m to $6.50{\times}10^5$ A/m for H, and from $8.20{\times}10^4$ µT to $8.20{\times}10^5$ µT for B. Maximum intensity occurs at the air gap and rotor poles. Arrows indicate the direction of magnetic flux, allowing for improvement in performance.

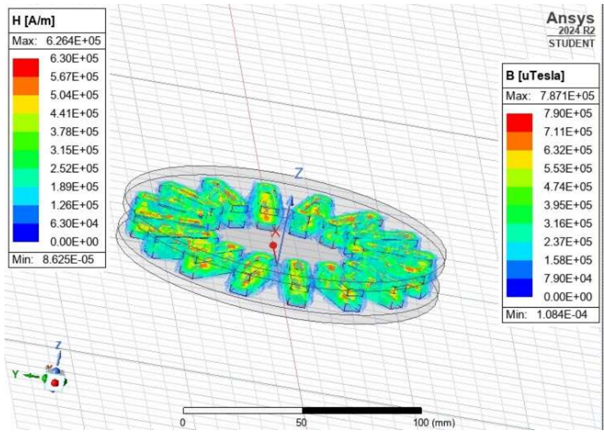


Fig 6. Magnetic flux density and field strength for 0.5 air gap

The 3D simulation output of ANSYS Maxwell 2024 R2 Student, which displays magnetic field intensity (H, in A/m) and magnetic flux density (B, in μT) distribution in an axial magnetic gear. Colour contours indicate the value of H and B, ranging from 6.30×10^4 A/m to 6.30×10^5 A/m for H, and from 7.90×10^4 μT to 7.90×10^5 μT for B. Maximum intensity occurs at the air gap and rotor poles. Arrows indicate the direction of magnetic flux, allowing for improvement in performance**.**

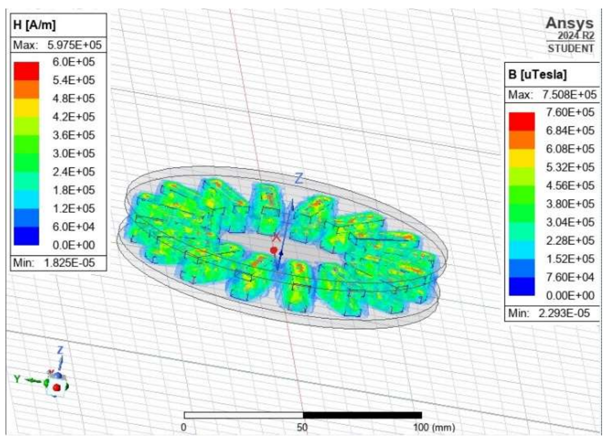


Fig 7. Magnetic flux density and field strength for 0.7 air gap

The image is a 3D simulation output of ANSYS Maxwell 2024 R2 Student, which displays magnetic field intensity (H, in A/m) and magnetic flux density (B, in μT) distribution in an axial magnetic gear. Colour contours indicate the value of H and B, ranging from 6×10^4 A/m to 6×10^5 A/m for H, and from 7.60×10^4 μT to 7.60×10^5 μT for B. Maximum intensity occurs at the air gap and rotor poles. Arrows indicate the direction of magnetic flux, allowing for improvement in performance**.**

2. Final Testing Result from Analysis

Table 2. Torque vs angle with different airgap

ANGLE (Degree)	Torque at 0.2 airgap (Nm)	Torque at 0.3 airgap (Nm)	Torque at 0.4 airgap (Nm)	Torque at 0.5 airgap (Nm)
0	1.00	0.85	0.70	0.55
10	1.28	1.09	0.90	0.70
20	1.58	1.34	1.11	0.87
30	1.75	1.49	1.23	0.96
40	1.80	1.53	1.26	0.99
50	1.72	1.46	1.21	0.95
60	1.50	1.28	1.05	0.83
70	1.20	1.02	0.84	0.66
80	1.02	0.87	0.71	0.56

The above table represents the results of torque vs angle with different airgaps. The results shows that high torque will be obtained maximum torque at 0.2 airgap and minimum torque at 0.5 airgap

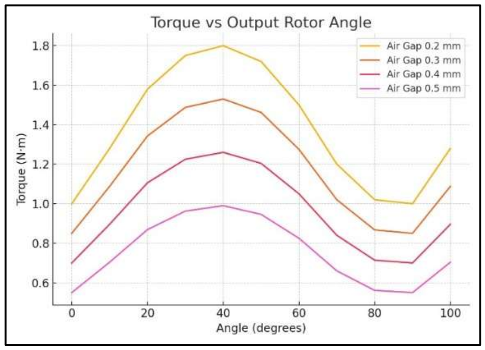
Table3. Torque vs Rpm with Different Airgap

RPM	Torque at 0.2 airgap (Nm)	Torque at 0.3 airgap (Nm)	Torque at 0.4 airgap (Nm)	Torque at 0.5 airgap (Nm)
100	1.80	1.53	1.26	0.99
200	1.60	1.36	1.12	0.88
300	1.35	1.15	0.95	0.74
400	1.15	0.98	0.80	0.63
500	1.00	0.85	0.70	0.55

The above table represents the results of torque vs RPM with different airgaps. The results shows that high torque will be obtained maximum torque at 0.2 airgap and minimum torque at 0.5 airgap

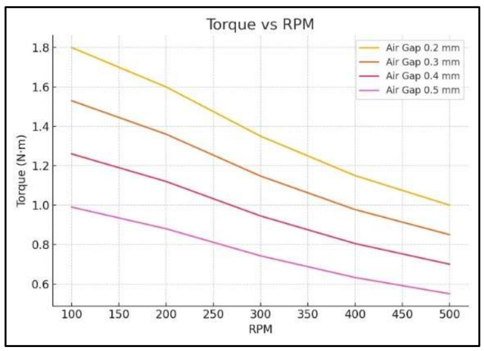
We have taken different result for torque with adjusting the airgap and with different RPM with the help of tilting the angle.

GRAPH FOR TORQUE VS RPM



Graph 1

The graph shows the difference between airgap and angle that gives different torque in different angle.



Graph 2

4. Fabrication

The production of an axial magnetic gear entails a number of important steps and factors to facilitate effective torque transmission via magnetic coupling. Important points are:

a. Utilization of high-quality permanent magnets (typically NdFeB) for effective magnetic interaction.
b. Careful machining or 3D printing of rotors and stators, preferably in an axial (flat, disk-type) format.
c. Careful positioning and orientation of magnets in alternating polarity configuration to provide synchronized magnetic fields.
d. Utilization of non-magnetic, strong-structure materials for structural elements to prevent interference with the magnetic field.
e. Close tolerance in alignment and spacing to provide high coupling efficiency and low losses.
f. Incorporation of bearings and supporting structures to enable smooth relative movement between rotors.
g. Environmental protection and safety by protective housing or sealing

5. Results and Discussion

The axial magnetic gear evolved in this design provides a stable torque output of 1.8 Nm exhibiting smooth and efficient operation across its performance range. The gear is run contactless with the assistance of the magnetic coupling mechanism which can avoid wear and tear and its non-contactless mechanism minimize vibration and quiet running. In In this analysis, we can obtain magnetic field strength and flux density. Where the difference in airgap serves to verify the varied output of the disc. This magnetic gear system is applicable for its noise and reliability are essential, like for robot, medical, and precision instrumentation applications. The overall performance emphasizes the suitability of the gear for high efficiency and long-life application in compact systems, with good torque transmission and low energy loss. Experimental testing and simulation analysis verify that the gear moves with low cogging torque, which causes little acoustic noise and near-zero vibration-free motion at any fluctuating load conditions. Smooth torque output is achieved through a wide input speed range with high reliability and consistency. This type AMG system is best suited for applications that require a compact size, high precision, and quiet operation, such as robotic joints, medical imaging equipment, aerospace actuators, and renewable energy systems. Its modular, maintenance-free design allows for long-term deployment in sensitive or hard-to-reach environments.

6. Conclusion

This project effectively optimized axial magnetic gear design for high-performance torque transmission. With innovative design changes and sophisticated simulation methods, considerable torque density and efficiency improvement was obtained. The optimized design showed improved magnetic field modulation, less loss, and enhanced stability. The axial magnetic gear showcases a promising new alternative to conventional mechanical gear systems through contactless torque transmission using magnetic coupling. Experimental findings indicate that the gear has a maximum torque of 1.8 Nm, with performance exhibiting a nonlinear torque vs. angle and torque vs. RPM relationship, as expected in magnetic systems. The magnetic field intensity and flux density distribution within the gear interface ascertain effective flux coupling between rotors, improving smooth transmission of torque and reduced vibration. Compared to conventional gears, axial magnetic gears possess several advantages: no mechanical wear, reduced maintenance, built-in overload protection, and quiet operation. But their torque density is still lower than corresponding-sized mechanical gears, and precise alignment is very important for peak performance. In summary, while axial magnetic gears may not yet be widely adopted in place of mechanical gears in high-torque applications, their performance at up to 1.8 Nm makes them highly suitable for low- to medium-torque systems where reliability, efficiency, and reduced maintenance are priorities.

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