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Magnetic Power Transmission

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Abstract: A magnetic gear functions in a manner similar to a mechanical gear, but it has magnets in place of teeth. The gears are really unusual because they never actually touch and instead communicate magnetically. The quantity of magnets employed in each rotor affects the "gear ratio". A 4:1 gear ratio is achieved if one rotor has 4 magnets while the other has 16. There are various types of topologies when we consider magnetic gear, for this study we are only focusing on axial topology of magnetic gears. These are contactless gears due to which there is more efficiency in transmission of power and torque and can be used in various fields where efficiency is preferred.

Index Terms **- magnetic gear, axial topology, magnet interaction, flux modulator**

I. Introduction

Throughout history, gearboxes have been the backbone of many types of machinery, from complex watches to large industrial machines. These gears helped transmit power and speed. However, traditional materials present their own set of challenges. Struggles cause energy loss, tooth damage, and often require repairs.

In response to these limitations, engineers and researchers have been increasingly interested in finding new technologies that can overcome these shortcomings and maintain the essential functions of gears The search for new solutions has led to emerging technologies, and one particularly promising approach is the development of magnetic gears. Magnetic gears represent a departure from conventional mechanical gears by harnessing the power of magnetism. This new approach aims to eliminate the shortcomings of conventional gears. Using magnetic fields, these gears offer the potential to dramatically increase efficiency, reduce friction-related losses, and reduce the need for routine maintenance Magnetic gears herald a paradigm shift in mechanical systems, and reproduces a well-established view of the gears to be dealt with the evolving design requirements of modern mechanical applications.

This shift in thinking not only reflects a commitment to overcoming historical challenges but highlights the adaptability and innovation of technology. As magnetic gears continue to be explored and refined, they hold the promise of revolutionizing how we approach power transmission and motion control in modern devices, ultimately creating a more effective sustainable future.

There are various types of topologies when we consider magnetic gears for this study we will be considering only axial topology of magnetic gears. Unlike conventional gears with physical teeth, magnetic gears use the principles of magnetism to transmit torque and motion, offering a novel approach to gear design and operation. This research paper explores the fundamental concept of magnetic gears in axial topology and delves into the pivotal role of magnet interactions in determining gear ratios. The magnetic gears in axial topology have a promising future for addressing long-standing challenges associated with traditional mechanical gears and open new levels for advanced mechanical systems.

II. Literature Survey

1] The literature gives information about various topologies of magnetic gears and applications of magnetic gears[1]
2] This research paper give information about various electromagnetic concepts and basic working principle behind magnetic gears[2]
3] These research papers gave us idea about how should we design our prototype and have information about designing of magnetic gears and magnetic transmission system.[4][5]
4] This research papers give detailed information about calculation of torque and angular velocity in magnetic gears.[7]

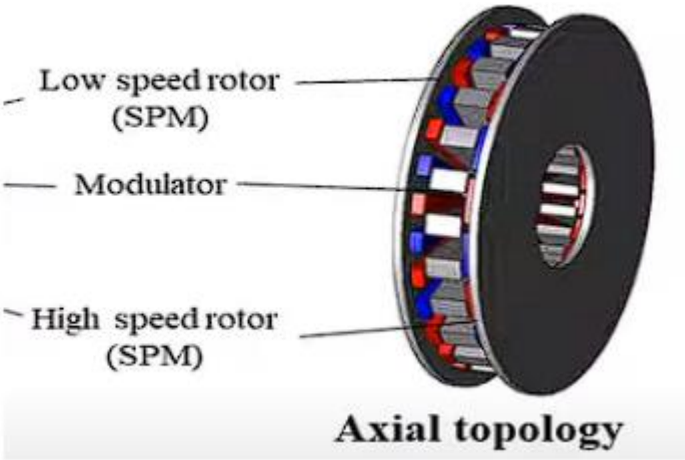

Fig. 1. Axial Topology gear design

III. RESEARCH METHODOLOGY

3. 1 Design dimensions

Given :
Magnet dimension : 20 X 4 X 2 mm
According to iterations
Total number of magnets on gear : 16
Total number of magnets on pinion : 16
Number of inserts on modulator : 10
According to this data :
1] Outer diameter of Gear : 90 mm
2] Outer diameter of Pinion : 90 mm
3] Diameter of shaft : 8 mm
4] Length of input and output shaft : 50 mm
5] Outer diameter of modulator : 90 mm
6] Diameter of inserts : 6 mm
7] Length of inserts : 5mm
8] Pitch diameter of inserts : 64 mm
9] Inner diameter of Bearing : 8 mm
10] Outer diameter of Bearing : 16 mm
11] Thickness of Bearing : 5 mm

3.2 Material for 3D printing:

Selection of PLA for printing.

Characteristic	Biodegradability	Environmental Impact	Ease of Printing	Cost	Strength	Flexibility
PLA	Yes	Low	Very Easy	Low	Moderate	Low
PETG	No	Medium	Easy	Moderate	High	Low to Moderate
Nylon	No	Medium	Moderate	Moderate	High	High
ABS	No	Medium	Moderate	Moderate	High	Low to Moderate
Characteristic	Impact Resistance	Chemical Resistance	Temperature Resistance			
PLA	Moderate	Low	Low			
PETG	High	High	Moderate			
Nylon	High	High	Moderate			
ABS	High	Low to Moderate	High			

Table. 1. Selection of Material

For printing of components of Gear
Polylactic acid (PLA) was chosen for 3-D printing magnetic gear parts due to its excellent combination of properties. PLA is known for its ease of use in 3-D printing, providing excellent adhesion and minimal corrosion. Furthermore, PLA is biodegradable and derived from renewable sources, making it an environmentally friendly choice. Its mechanical properties, including adequate strength and durability, make it suitable for standard magnetic gear components. The affordability and wide availability of PLA

further contributes to its selection, providing a cost-effective solution for the specific requirements of magnetic gear systems without compromising performance.

3.3 Magnets:

Selection of Neodymium Magnets for printing :

Characteristic	Neodymium Magnets	Ceramic Magnets	Alnico Magnets
Strength	Very High	Low to Moderate	Moderate to High
Size and Weight	Small and Light	Bulky and Heavy	Moderate
Versatility	Highly Versatile	Limited Shapes	Limited Shapes
Temperature Resistance	Moderate	Good	Good
Cost	Relatively High	Low to Moderate	Moderate

Table. 2. Selection of Magnets

20x4x2 neodymium magnets were selected for the magnetic gear components due to their unique magnetic properties and compact dimensions Neodymium magnets are known for their high magnetic strength, which allows for smooth power flow in the gear system. Its specific size (20x4x2) strikes a balance between providing adequate magnetic strength and compactness, which is essential for optimizing the size and performance of the gear mechanism Furthermore, neodymium magnets exhibit strength and durability demonstrated, providing reliable long-term performance. The compact dimensions of the magnets contribute to the overall efficiency of the magnetic gear system, allowing for flexible and spatially efficient deployment within the constraints given in the application.

3.4 Bearings:

The selection of a circular bearing of 8 mm diameter, 16 mm width and 5 mm width for the application is based on considerations of size, load-carrying capacity and standards. These parameters are generally available and with accepted standards to size meets, which are easily available for production and replacement. The 8x16x5 mm round bearings strike a balance between compactness and weight-bearing capacity, fitting well within application design constraints, and providing sufficient strength to handle anticipated loads Standardized sizing also provides flexibility with materials and existing compatibility and facilitate system-wide integration. This system ensures reliability and efficiency of the ball bearing within the parameters specified in the application.

3.5 Selecting the Gear Ratio:

no of magnet	pairs	no of poles	
10	1	10	5N & 5S
	2	5	3N & 2S
	5	2	1N & 1S
11	1	11	NP
	11	1	
12	1	12	6N & 6S
	2	6	3N & 3S
	3	4	2N & 2S
	4	3	2N & 1S
	6	2	1N &1S
13	1	13	NP
	13	1	
14	1	14	7N & 7S
	2	7	4N & 3S
	7	2	1N & 1S
15	1	15	8N & 7S
	5	3	2N & 1S

no of magnet	pairs	no of poles	
16	1	16	8N & 8S
	2	8	4N & 4S
	4	4	2N & 2S
	8	2	1N & 1S
17	1	17	NP
	17	1	
18	1	18	9N & 9S
	2	9	5N & 4S
	3	6	3N & 3S
	6	3	2N & 1S
	9	2	1N & 1S
19	1	17	NP
	19	1	
20	1	20	10N & 10S
	2	10	5N & 5S
	4	5	3N & 2S
	5	4	2N & 2S
	10	2	1N & 1S

no of magnet	pairs	no of poles		
21	1	21	11N & 10S	
	3	7	4N & 3S	
	7	3	2N & 1S	
22	1	22	11N & 11S	
	2	11	6N & 5S	
	11	2	1N & 1S	
23	1	23	NP	
	23	1		
24	1	24	12N & 12S	
	2	12	6N & 6S	
	3	8	4N & 4S	
	4	6	3N & 3S	
	6	4	2N & 2S	
	8	3	2N & 1S	
	12	2	1N & 1S	
25	1	25	NP	
	5	5		

no of magnet	pairs	no of poles	
26	1	26	13N & 13S
	2	13	7N & 6S
	13	2	1N & 1S
27	1	27	13N & 14 S
	3	9	5N & 4S
	9	3	1N & 2S
28	1	28	14N & 14S
	2	24	12N & 12S
	4	7	4N &3S
	7	4	2N & 2S
	14	2	1N & 1S
29	1	29	NP
	29	1	
30	1	30	15N &15S
	2	15	8N & 7S
	3	10	5N & 5S
	5	6	3N &3S
	6	5	3N &2S
	10	3	2N & 1S
	15	2	1N & 1S

Table 3. Selecting the Gear Ratio

Process of 3-D Printing :

The 3-D printer used for 3-D printing the components was Lulzbot Taz 6 which was controlled by software Cura Lulzbot version 3.6.36.

The printing process was done on default settings except for :

1] Material : PLA was selected at default settings which were,

Hot End: 205°C

Bed: 60°C

Part Removal: 45°C

2] Infill : Since the rotor and modulator were expected to rotate at high speed infill was selected as 30%

3] High Detail was enabled to get high accuracy of dimensions of components

4] Support was enabled for printing of specific components

5] Inner diameter was changed to 1.75 mm.

The system of magnetic gear consists of 3 main parts as follows :

A. Flux Modulator

The flux modulator is a crucial component in magnetic gears, and its working involves the manipulation of magnetic field lines to facilitate efficient torque transfer between the two magnet holders. Here's a detailed explanation of how the flux modulator operates:

Cylindrical Structure: The flux modulator is typically a cylindrical or annular structure made from a non-magnetic material, such as stainless steel or aluminum. It is designed to fit snugly between the two magnet holders, creating a magnetic circuit that spans from one magnet holder to the other through the modulator.

Steel Inserts: Inside the flux modulator, there are ten strategically placed steel inserts. These inserts are carefully positioned at specific locations within the modulator. Their role is to act as "flux bridges." When magnetic flux lines encounter these inserts, they preferentially follow the path provided by the steel inserts rather than taking a more direct route through the air or the non-magnetic material of the modulator. This phenomenon is a fundamental aspect of magnetic field manipulation.

Influencing Magnetic Field Lines: As the magnets in the two holders generate magnetic fields, these fields extend into the flux modulator. When the magnetic field lines reach the steel inserts, they are attracted to the steel's high permeability, which provides a path of lower reluctance (resistance to the magnetic field) compared to the surrounding non-magnetic material. Consequently, the magnetic field lines are "channeled" or "guided" by the steel inserts, effectively following their contours.

Enhancing Magnetic Coupling: By channeling the magnetic field lines, the steel inserts in the flux modulator enhance the magnetic coupling between the two magnet holders. This manipulation of the magnetic field lines increases the efficiency of torque transfer from one holder to the other. The magnetic field lines effectively bridge the gap between the two holders through the modulator, even though there is no physical contact between the holders themselves.

Determining Gear Ratio: The specific arrangement and positioning of the steel inserts within the flux modulator, as well as the number and configuration of magnets in the two holders, play a crucial role in determining the gear ratio. By adjusting these parameters, engineers can tailor the magnetic gear system to achieve the desired gear ratio and torque characteristics for a given application.

Fig. 2. Flux Modulator Design

B.Gear

The Gear with 16 Magnets (Gear) in a magnetic gear is a fundamental element that plays a vital role in the efficient operation of the system.

Here's a detailed explanation of how the Gear works:

Arrangement of Magnets: This component houses a set of 16 permanent magnets, typically arranged in an axial or circular fashion, depending on the specific design of the magnetic gear. It's crucial to note that these magnets are arranged in an alternate north (N) and south (S) configuration around the holder's circumference. This arrangement creates a magnetic field that is characterized by alternating north and south poles along the perimeter.

Magnetic Field Generation: When the magnetic gear is in operation, these 16 magnets generate magnetic fields that extend into the flux modulator, which is positioned adjacent to the magnet holder. The magnetic field lines emanating from the north poles of these magnets interact with the steel inserts in the flux modulator, thanks to their attractive force.

Interaction with Flux Modulator: The orientation and configuration of the magnets are precisely designed to interact with the steel inserts within the flux modulator. As the magnetic field lines reach the flux modulator, they are guided and channeled by the steel inserts. The steel inserts effectively influence the path of these field lines, making them follow a particular route dictated by their strategic placement.

Torque Transfer: As the magnetic field lines pass through the flux modulator, they establish a magnetic coupling with the Pinion on the other side of the flux modulator. This magnetic coupling enables torque to be transferred from the first Gear (Gear) to the second magnet holder, even though there is no physical contact between the holders themselves. One south and its adjacent North pole acts as a gear tooth.

Gear Ratio Determination: The number of magnets in this gear (16, in this case), their arrangement, and the magnetic polarity play a pivotal role in determining the gear ratio of the magnetic gear system. The gear ratio represents how many rotations the first holder must make for the second holder to complete one full rotation. In this scenario, the specific arrangement of 16 magnets and their alternating north-south polarity configuration helps define a 4:1 gear ratio.

Fig. 3. Design Gear

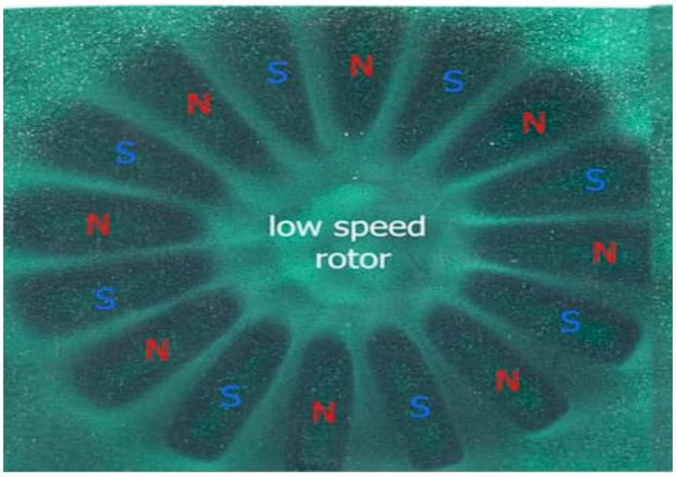

Fig. 4. Arrangement of Magnets in Gear

C.Pinion

The Pinion with 16 Magnets in pairs of 4 North and 4 South which effectively acts as 4 large magnets (Pinion) is a crucial part of the magnetic gear system, and its operation complements that of the Gear (Gear).

Here's a detailed explanation of how the second Pinion works:

Magnet Configuration: The Pinion accommodates a set of four permanent magnets, akin to the first holder. These magnets are also arranged with alternating north (N) and south (S) poles along the holder's circumference. This arrangement is consistent with the principle of alternating polarity to optimize magnetic field interactions.

Magnetic Field Generation: When the magnetic gear is in motion, the four magnets in this holder generate their respective magnetic fields. These fields extend toward the flux modulator, which is positioned on the opposite side of the magnet holder. Importantly, the alternating north-south configuration of these magnets creates a magnetic field with alternating polarity, mirroring the setup of the first magnet holder.

Interaction with Flux Modulator: Just as with the first magnet holder, the magnetic field lines generated by the second holder interact with the steel inserts within the flux modulator. The steel inserts channel and influence the path of these field lines due to their attractive properties. Here, the alternating north-south configuration of the magnets in the second holder is critical because it complements the alternating magnetic field lines, enhancing their interaction with the steel inserts.

Gear Ratio and Torque Transfer: The four magnets in this holder, with their distinct configuration and reduced number compared to the first holder's magnets, contribute to determining the gear ratio of the magnetic gear system. In the specified design, the smaller number of magnets and their alternating polarity configuration establish the desired 4:1 gear ratio. This gear ratio signifies that for every full rotation of the first magnet holder, the second holder completes one-fourth of a rotation. The combination of 4 magnets acts as one effective big magnet.

Tolerance was observed to be 100 microns on cover and rotors where bearings are press fitted.


Fig. 5. Design of Pinion

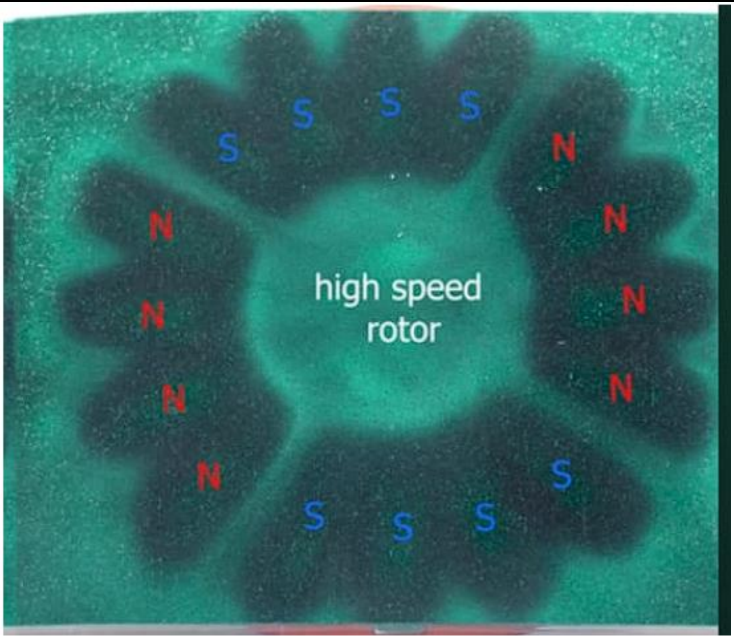

Fig. 6. Arrangement of magnets in Pinion

Operational Principal

D. Magnetic Interaction and Magnetic Coupling:

The core of axial magnetic gears lies in magnetic interaction, where magnetic fields generated by the magnets in the holders interact with the steel inserts in the flux modulator. When a rotary motion is applied to one of the magnet holders, such as Gear with 16 magnets, it generates a magnetic field. This magnetic field extends into the flux modulator, where it encounters strategically positioned steel inserts. The steel inserts act as flux bridges, channeling and influencing the path of the magnetic field lines. Importantly, these field lines are guided by the steel inserts, creating a magnetic coupling between the first and second magnet holders, even though there is no physical contact between them. The steel inserts serve to effectively "communicate" the magnetic forces between the holders, allowing torque to be transmitted without direct mechanical contact.

E. Principle of operation of Magnetic gears:

Equations

Ns = pout + pin

(Ns) * (Ws) = (pout) * (ωout) + (pin) * (ωin)

Therefore, at fixed iron pieces

Wout/Win = - pin/pout = Tin/Tout = Gear ratio(Gr)

1] Calculation of torque

Gearing affect torque = Tout = Gr * Tin

Output Torque = Gr * Input Torque

2] Calculation of angular velocity

Output angular velocity = Gr * Input angular velocity.

where the pin is the pole pair of input rotor, Ns is the steel inserts in the flux modulator, and pout are the number of poles pair of output rotor. The correspondences between the output (ωout) and input (ωin) speed and the gear ratio (Gr)

For our Case :

Pole Pairs in Gear : 8 = pin

Pole Pairs in Pinion : 2 = pout

No. of inserts : 10 = Ns - pin/pout = Tin/Tout = Gear ratio(Gr) = 8 / 2 = 4

Therefore,

Output Torque = 4 * Input Torque

Output angular velocity = 4 * Input angular velocity

F. Dependency on Components :

All three components, the Flux Modulator, Gear (16-magnet holder), and Pinion(4-magnet holder), are intricately dependent on each other for the proper operation of the axial magnetic gear system.

The arrangement and polarity of the magnets in the holders are designed to complement the steel inserts in the flux modulator. The flux modulator's strategic placement between the magnet holders ensures that it serves as a bridge for the magnetic field lines, facilitating their redirection and coupling. The gear ratio, which defines how much one holder rotates relative to the other, is determined by the number, arrangement, and polarity of magnets in the holders. In this described setup, the 16 magnets in Gear and the 4 magnets in Pinion establish a 4:1 gear ratio.

G. Advantages and Applications:

Axial magnetic gears offer several advantages over traditional mechanical gears. These include reduced friction since there is no physical contact, minimal wear and tear, and the potential for higher efficiency. Reduced friction results in less energy loss during operation, making axial magnetic gears suitable for applications where energy efficiency is critical. The absence of physical contact between components leads to reduced maintenance requirements and longer operational lifetimes, making them suitable for applications in industries such as robotics, aerospace, and renewable energy.

IV. RESULTS AND DISCUSSION

4.1 Cad Modelling and Assembly

1. **Rotor**

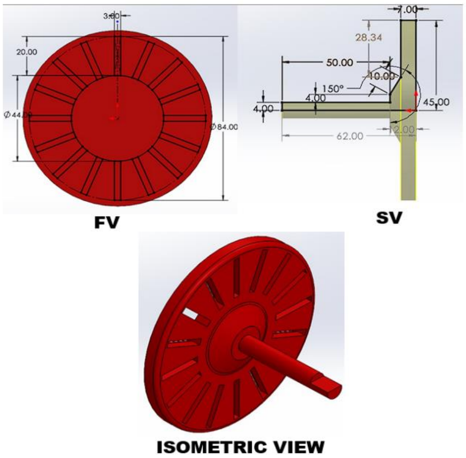

Fig. 7. Rotor

2. **Modulator**

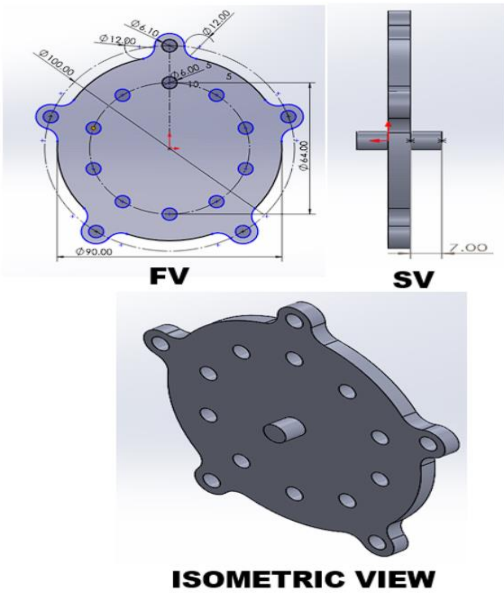

Fig. 8. Modulator

3. **Cover**

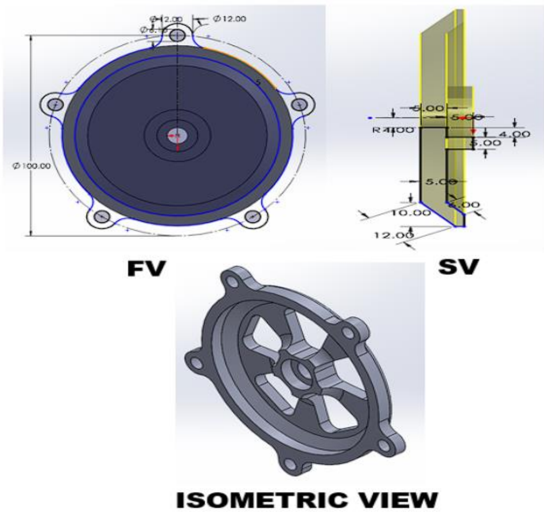

Fig. 9. Cover

4. Assembly

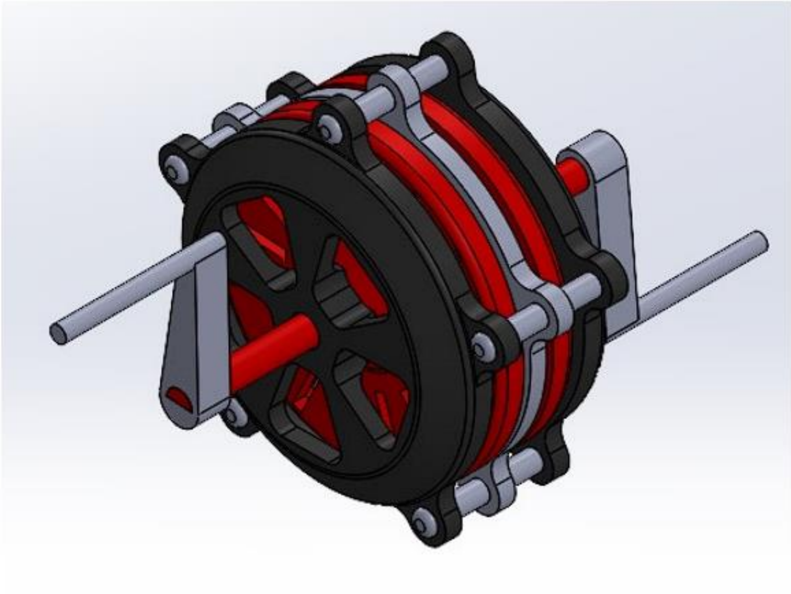

Fig. 10. Isometric view of Assembly

Result

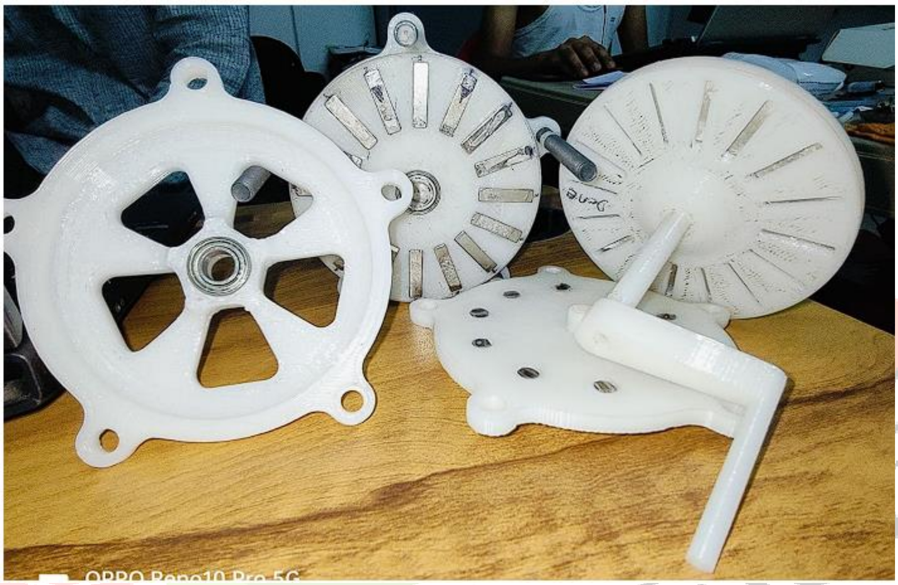

Fig. 11. All components of Gear

Fig. 12. Assembly of components

V. ACKNOWLEDGMENT

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REFERENCES

[1] Ruiz-Ponce, G., Arjona, M. A., Hernández, C., & Escarela-Pérez, R. (2023, February 9). A Review of Magnetic Gear Technologies Used in Mechanical Power Transmission. Energies. https://doi.org/10.3390/en16041721

[2] Da Costa Neves, C. G. (2017, January 1). Magnetic Gearing Electromagnetic Concepts. ResearchGate. https://www.researchgate.net/publication/316325959_Magnetic_Gearing_Electromagnetic_Concepts

[3] Magnetic gear technologies: A review. (2014, September 1). IEEE Conference Publication | IEEE Xplore. http://dx.doi.org/10.1109/ICELMACH.2014.6960233

[4] Li, F., Zhao, H., & Su, X. (2024, January 1). Design of an Axial-Type Magnetic Gear with Auxiliary Flux-Enhancing Structure. MDPI. https://doi.org/10.3390/en17092207

[5] Design And Fabrication Of Gear, Hineeth kumar SP, Karthik N Gowda, Yogesh S , Likith S, Nandini S, International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 09 Issue: 06 | Jun 2022 p-ISSN: 2395-0072. https://www.irjet.net/archives/V9/i6/IRJET-V9I6518.pdf

[6] Abdel‐Khalik, A. S., Ahmed, S., & Massoud, A. M. (2014, September 1). A bearingless coaxial magnetic gearbox. Alexandria Engineering Journal /Alexandria Engineering Journal. https://doi.org/10.1016/j.aej.2014.06.002