Guwahati, Assam

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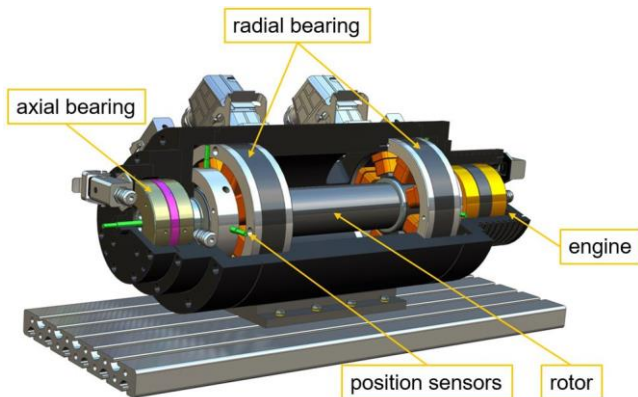November 16, 2023

Contents

Introduction to Magnetic Bearings

Revolutionary Devices in Precision Manufacturing

- Magnetic bearings eliminate contact, reduce friction, and enable nearly frictionless movement.
- They handle high rotational speeds, enhancing system performance and longevity.
- Ideal for systems requiring high precision and low maintenance.

High-Performance and Extended Lifespan

- Support heavy loads without physical contact through electromagnetic force.
- Operate at high speeds with minimal deviation from the center.
- Radial magnetic bearings provide stability and axial suspension.
- Classified as homopolar or heteropolar, depending on the direction of the magnetic poles.
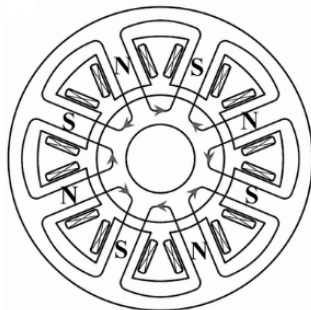

Figure: 8 pole Heteropolar NSNS Magnetic Bearings

Mathematical Foundations

Mathematical Modeling - Core Principles

- **Magnetic Force Calculation:**
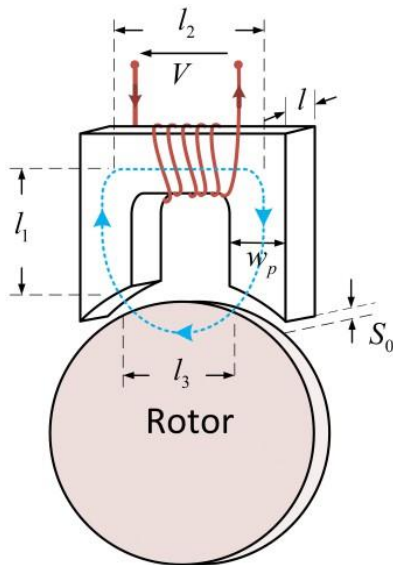   - The fundamental equation for load capacity:

        $F_{max} = \frac{B_j^2 A_p}{2\mu_0} \sin \vartheta_j$
    - Establishes how magnetic flux density B_j translates into vertical force.
- **Ampere's Law and MMF:**
    - $H_{mag} \cdot dl = N I = MMF$
    - Connects electric current to the actuator's magnetic field generation.
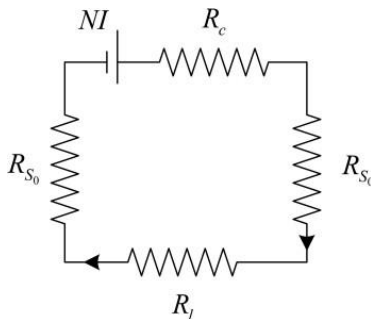
Mathematical Modeling - Magnetic Flux and Reluctance

- **Magnetic Flux Density:**
  - $B_j = \mu_0 \mu_r H$
  - Dependent on material properties, crucial for actuator design.
- **Reluctance and Displacement:**
  - $R_{s0} = \frac{S_0 - x_m}{\mu_0 \mu_r A_p}$
  - Relates air gap reluctance to displacement, impacting magnetic circuit flux.

Mathematical Modeling - Flux Linkage

- **Flux Linkage Equation:**
  - $\Psi = \frac{N^2 \mu_0 \mu_r w_p l_c I}{2 S_0 - x_m}$
  - Defines the interaction between coil properties and electric current, influencing magnetic field production.
- **Application in COMSOL:**
  - Utilization of these equations for finite element modeling within COMSOL.
  - Allows for simulation and performance prediction, essential for design optimization.
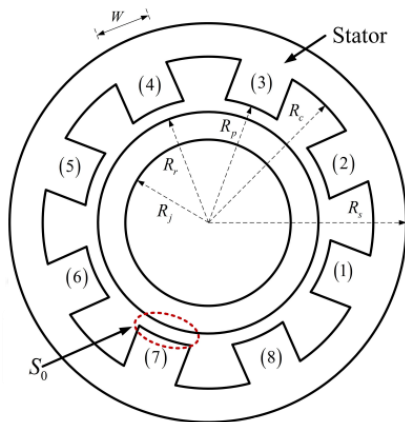
Methodology

Methodology - Initial Setup

Generating Geometry of the Magnetic Bearing

- These electromagnets are positioned around the axis, forming an octagonal pattern.
- The fundamental principle behind this geometry is to generate a balanced magnetic force that counters any displacements in the object's position, ensuring it remains suspended with minimal deviation.

Parameter	Value
Rotor Radius (r)	28.8 mm
Journal Radius (rj)	40 mm
Radius of Pole Faces (rp)	41.1 mm
Radius of depth of coils (rc)	66 mm
Stator Outer Radius (rs)	77.2 mm
Width of the Pole (wp)	22.32 mm
Mean Air Gap	1.1352 mm
Pole Surface Area	1200 mm²

Table: Dimensions of Magnetic Bearing

Modelling Geometry and Material Properties

To recreate the geometry of the magnetic bearing itself, the measurements from Table 1 are utilized. After creating the geometry within COMSOL, the geometric model can only be used if materials are defined for all domains. Below is a colored image of the geometry that helps assign the materials.
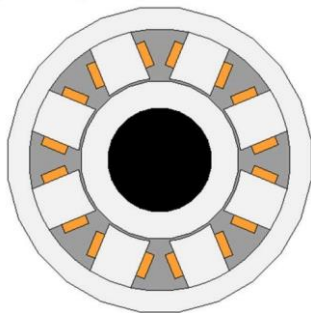
Allocating Materials in Multiphysics Software

Domains	Material	Color
Windings of the slots	Copper	Orange
Slots, Stator, Outer sheath of Rotating shaft	Soft Iron	White
Rotating Shaft	Structural Steel	Black
Between Slots, Air Gap	Air	Grey

Table: Allocating materials in Multiphysics Software

The Soft Iron used to model this magnetic bearing has the relative μ_r = 1000 for modeling purposes because an ideal value of 1 would void the solvers, and the model would not function.

Modelling Steps - Simulation Execution

Configuration of Coils Used in the Model:

Material Type	Solid
Conductor Model	Homogenized Multifilament
Current	5A (sinusoidal)
Number of Turns	160
Round wire diameter	1.22mm

Table: Configuration of coils used in the model

Rotating Shaft Domain: The rotating shaft is assigned a rotating domain so that its effects can also be studied. This includes the interaction of the shaft with the magnetic field and its impact on the overall system behavior.

Results and Discussion

Results and Discussion

For the model simulation, mesh size was varied from coarse to fine to normalize the results. The following are the results of the simulation.

Comparative Study between Different Mesh Sizes

- Simulations were performed with different mesh sizes to understand their impact on the results.
- "Fine" mesh size offers a detailed insight into the magnetic flux density distribution.
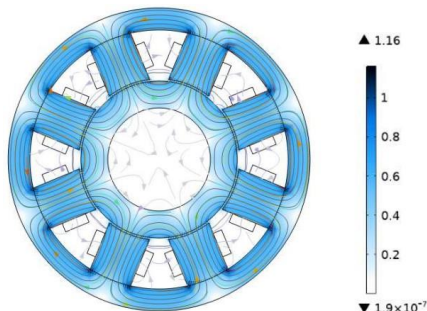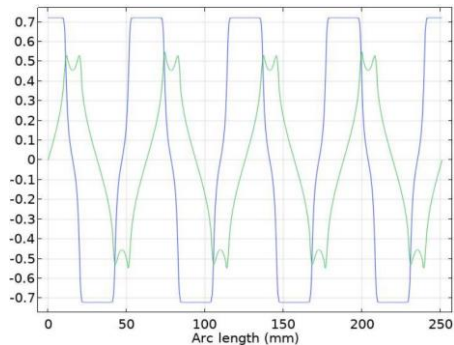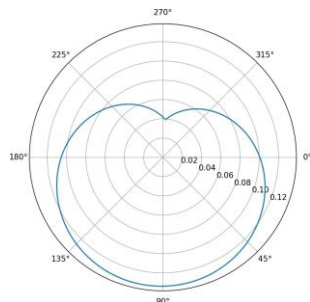

Figure: Magnetic Flux Density for Fine Mesh size

Results of "Fine" Mesh

Plot of Magnetic Flux Density for Radial
(Purple) and Tangential (Tangential)
axis for Fine Mesh size

Polar Plot of Electromagnetic
Forces in X and Y direction

Comparative Study between Different Mesh Sizes (Continued)

- The "Normal" mesh is used as a standard reference for the simulation.
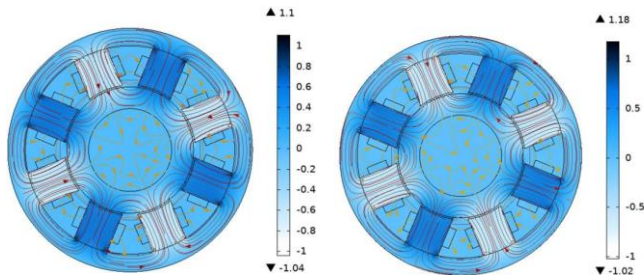- The "Coarse" mesh provides a less detailed but quicker simulation result.

Figure: Magnetic Flux density for (a) "Normal" Mesh size and (b) "Coarse" Mesh size.

Mesh Size Impact on Simulation Results

- Analysis of flux density plots shows the influence of mesh granularity on the magnetic field simulation.
- Fine mesh size results in higher resolution and more accurate modeling of the magnetic field behavior around the bearing.
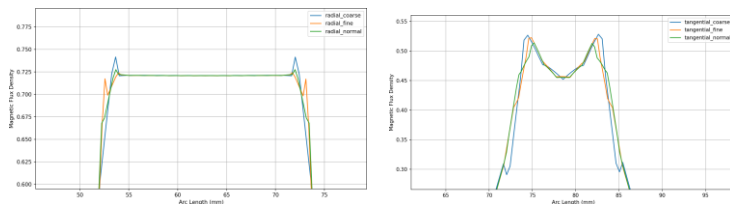

Figure: Magnetic Flux density for (a) "Radial" direction and (b) "Tangential" direction.

Force Analysis with Current Variation

Force Analysis with Current Variation - Introduction

To ensure that the model can balance the rotating shaft properly, it is crucial to demonstrate the effect of imbalances in current. These imbalances create a net force in the direction of increase, critical for the model's accuracy in simulating real-world physical behavior.
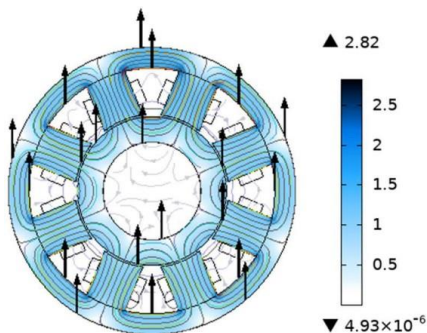

Figure: Plot of Force and its direction with simulated current variation

Force Analysis with Current Variation - Detailed Discussion

Figure illustrates the magnetic flux density of the Magnetic Bearing when the current is increased to 6A in coil B. This visualization shows the direction of the forces that result from the increase in current, which is non-zero and predominantly in the positive y-direction. The impact of these forces is further elucidated by the plots of Radial and Tangential electromagnetic forces, which reveal the effects on the outer portions of the rotating shaft.
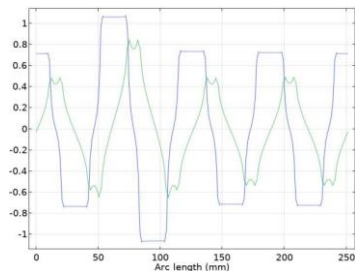

Figure: Plot of Force and its direction with simulated current variation

Force Analysis with Current Variation - Conclusion

These force vectors are crucial for maintaining the stability of the rotating shaft. The analysis of force direction and magnitude aids in understanding how the model behaves under varied electrical input and helps in the fine-tuning of the magnetic bearing design for optimal performance.
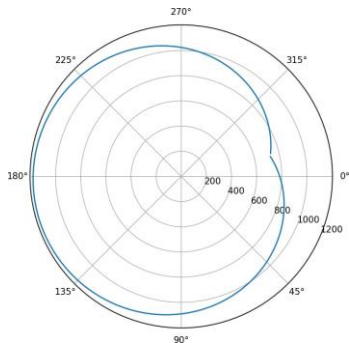

Figure: Plot of Force and its direction with simulated current variation

Conclusion and Future Work

Conclusion

- Explored PMBs via COMSOL Multiphysics with noted advantages of low friction and maintenance.
- Faced challenges including low stiffness and significant axial forces.
- Detailed understanding of PMB dynamics achieved, from magnetic flux distribution to force impacts.
- Provided insights into system stability and frequency response.
- Laid groundwork for future PMB engineering advancements.

Future Work

- Model to be integrated with complex circuits for error prevention and precise shaft centering.
- Future developments to include:
    1. Empirical validation of the numerical model.
    2. Overcoming drawbacks of new bridge configured winding scheme.
    3. Generalization of design guidelines for balance and stability.

Thank you!