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DESIGN AND ANALYSIS OF HYBRID MAGNETIC BEARINGS FOR HIGH-SPEED SPINDLE

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Abstract: High-speed spindles play a crucial role in modern manufacturing, demanding precision, stability, and durability. Magnetic bearings are increasingly employed to overcome limitations associated with conventional mechanical bearings. This paper presents the design and analysis of a hybrid magnetic bearing system tailored for high-speed spindle applications. The pursuit of stable, low-friction, and high-speed support in rotating machinery like milling machine prompts the development of hybrid magnetic bearings. Traditional mechanical bearings, while effective, suffer from wear and friction due to physical contact. Conversely, purely magnetic bearings offer contact-free support but demand precise control systems for stability. The design process focuses on bearing geometry, and control strategies to demands of high-speed spindles. It involves studying rotational speed, axial and radial loads, and operating temperatures, assessing trade-offs between design parameters. The study employs computational fluid dynamics (CFD) simulations to evaluate structural integrity of the hybrid magnetic bearing system. the design and analysis of hybrid magnetic bearings for high-speed spindles present an innovative solution to precision engineering challenges. The active and passive magnetic bearings enhance system reliability and stability, promising a technological leap for future high-speed spindle applications.

***Index Terms* - Traditional Bearings, Hybrid Magnetic Bearing, High Speed Spindle, CFD, Analysis.**

I. INTRODUCTION

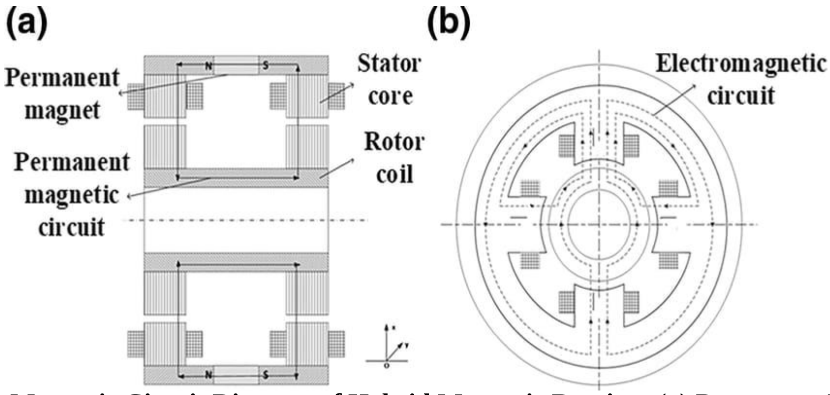
The development of advanced bearing systems has been a pivotal focus in high-speed spindle applications, significantly influencing performance, efficiency, and durability in modern manufacturing. The integration of hybrid magnetic bearings (HMBs) addresses the limitations of traditional mechanical bearings by providing contact-free support, minimizing friction and wear, and enhancing overall system stability and reliability [1]. The cutting force dynamics in high-speed milling processes, specifically focusing on aluminium alloy impellers, highlighting the necessity for precision and stability in bearing systems [2]. Exploring the design and analysis of bearing less flywheel motors, emphasizing their applicability in energy storage and demonstrating the relevance of magnetic bearings in high-speed rotational systems. Where in applying FEM softwares to analyse active magnetic bearings, providing a foundational framework for computational modelling in this domain [3].

As developed a miniature milling spindle equipped with active magnetic bearings, showcasing the feasibility and advantages of miniaturized bearing systems in enhancing spindle performance [4]. The optimization and transient-state analysis of active magnetic bearings using ANSYS, contributing to the understanding of dynamic behaviours and control strategies[5],which presents a multi-hybrid active magnetic bearing design for milling spindle applications, offering insights into the integration and performance benefits of hybrid systems[6].

Upon simulation and analysing hybrid magnetic bearings for high-speed spindles, that emphasizes the importance of simulation tools in predicting system behaviour under various operating conditions [7]. Reportedly the development of high-speed spindles with magnetic bearings, underscoring the advancements in machine tool applications are the potential for improved manufacturing processes [8]. That helped in evolution of a new design for a hybrid-type self-bearing motor for small, high-speed spindles, highlighting innovations in motor design and their implications for bearing performance [9].

As analysed hybrid magnetic bearings for high-speed spindles, focusing on material science and engineering aspects to enhance bearing capabilities. [10]. The experimental verification of hybrid magnetic bearing operations, validating theoretical models and simulation results through practical implementation, has been added advantage [11] and [13]. With developed time-domain simulation models for hybrid magnetic bearing characteristics, which there by contributes the accurate prediction and optimization of bearing behaviour in real-time applications[14].

Proposed a novel 4-DOF hybrid magnetic bearing for DGMSCMG, demonstrating the advanced control and flexibility offered by modern magnetic bearing designs [15]. Overall, these studies collectively advance the field of magnetic bearings, highlighting the continuous innovation and practical applications that drive the development of high-performance systems.



"Fig 1: Magnetic Circuit Diagram of Hybrid Magnetic Bearing; (a) Permanent Magnetic Circuit; (b) Electromagnetic Circuit

.**Design & Modelling of Hybrid Magnetic BeaRing**

The systematic strategy or collection of techniques used to carry out research, solve an issue, or accomplish a particular objective is referred to as methodology. The context and the nature of the task at hand will determine which methodology is best for you. In general, methodology acts as a road map to help you navigate the challenges of a job or project. It offers the basis for growth, accuracy, and consistency—all of which are necessary to produce favourable results and enhance knowledge and practice across a range of fields.

2.1 Consideration of design parameters: The precise, measurable characteristics that specify a system's or component's performance and configuration are known as design parameters. They serve a vital role in directing the development, analysis, and optimization of designs since they contain quantifiable attributes including dimensions, material qualities, and operating conditions. When design parameters are picked carefully, systems are guaranteed to run dependably, satisfy performance goals, and adhere to external restrictions and specifications. Important design factors for hybrid magnetic bearings used in high-speed spindles are the stator pole surface area, air gap length, magnet area, magnet thickness, stator ring thickness, and the inner and outer diameters of the stator ring. These factors all work together to affect the efficiency, performance, and dependability of the system.

- Stator Pole Surface Area: Influences the strength and distribution of the magnetic field.
- Air Gap Length: Affects magnetic force generation and system precision.
- Magnet Area: Determines the overall strength and uniformity of the magnetic field.
- Magnet Thickness: Impacts the field strength and mechanical properties of the system.
- Statoring Thickness: Relates to the structural integrity and thermal management.
- Statoring Outer Diameter: Influences the size and compatibility of the bearing system.
- Statoring Inner Diameter: Defines the rotor accommodation and air gap precision.

	STATOR (mm)	ROTOR (mm)
SURFACE AREA	218	125
OUTER DIAMER	80	50.24
INNER DIAMETER	68.74	60
THICKNESS	5.63	4.868
AREA OF MAGNET	195	110
THICKNESS OF MAGNET	6.29	5.522
AIR GAP	0.762	0.762

Table 1: values of components.

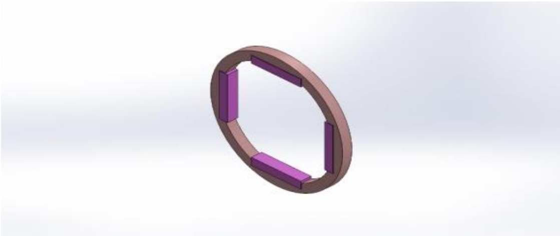


Fig2: Stator and Magnet

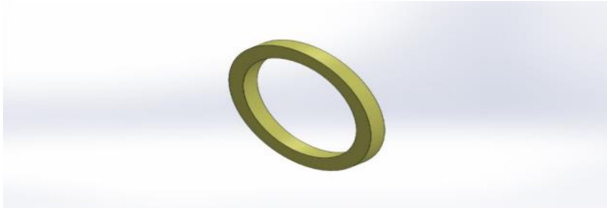


Fig3: Rotor

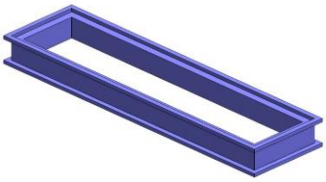


Fig4: Coil

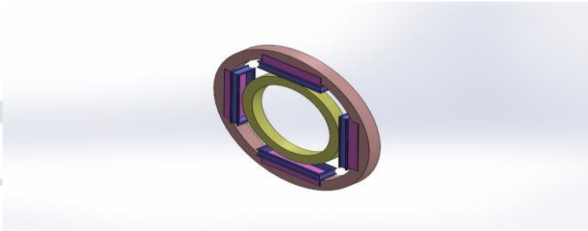


Fig5: Assembly of Hybrid Magnetic Bearings

Modelling of the components using Solidworks where in different parts are modelled and assembled for the analysis purpose.

II. ANALYSIS OF HYBRID MAGNETIC BEARING

Integrating SolidWorks Flow Simulation with Computational Fluid Dynamics (CFD) analysis can significantly improve your simulations' performance, particularly when handling fluid dynamics inside or around solid objects.

SolidWorks Flow Simulation is an effective tool for simulating fluid flow and heat transfer processes using computational fluid dynamics (CFD). You may examine the behavior of fluids (liquids and gases) in SolidWorks Flow Simulation by using CFD to model real-world scenarios including fluid mixing in a tank, heat transfer in a heat exchanger, and airflow over a surface.

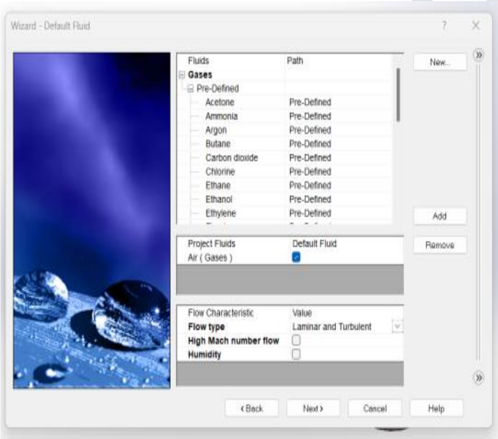


Fig6: Air

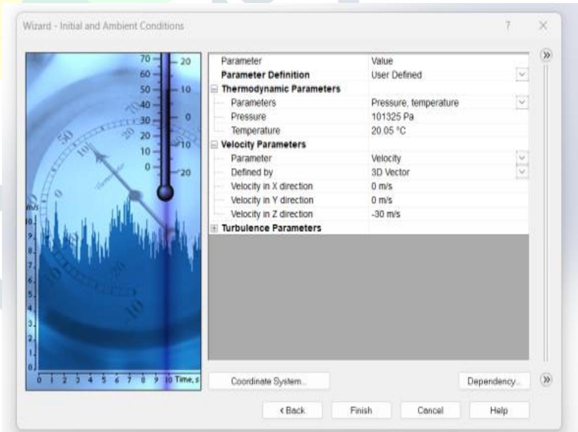


Fig7: Boundary Conditions

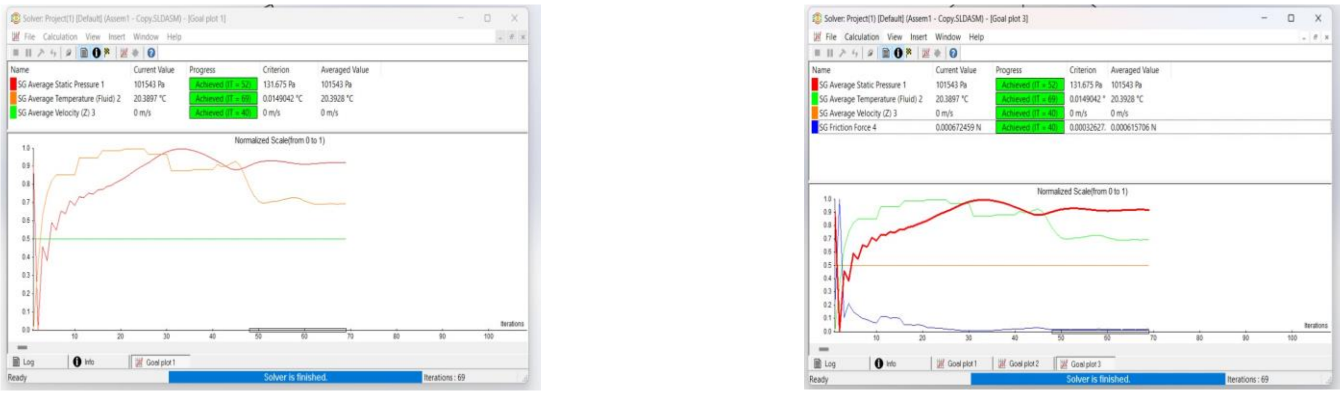


Fig 8: Surface Goals

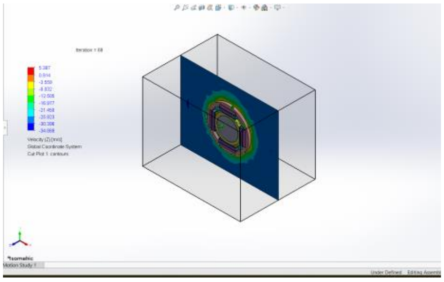


Fig 9: Velocity - Cut Plot

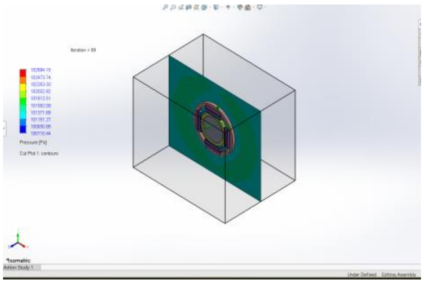


Fig 10: Pressure - Cut Plot

Velocity [Z]m/s value	**34.669**
Pressure[pa] value	100710.4

Table 2: values of Cut Plot

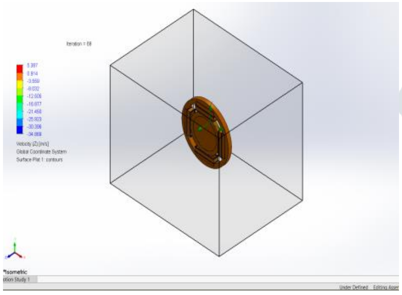


Fig 11: Velocity - Surface Plot

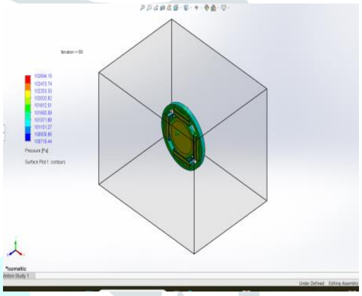


Fig 12: Pressure - Surface Plot

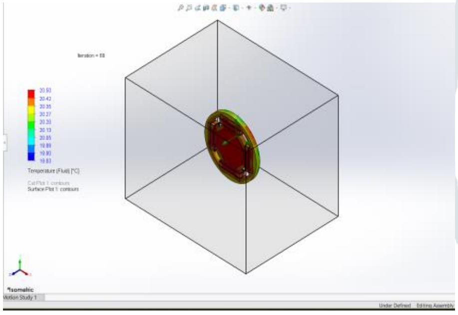


Fig 13: Temperature (Fluid) - Surface Plot

Velocity	**34.867**
Pressure	100710.4
temperature	19.83

Table 3: values of Surface Plot

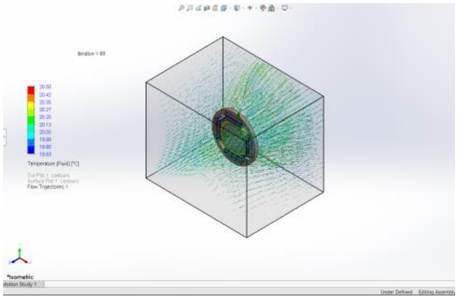


Fig 14: Temperature Flow Trajectories

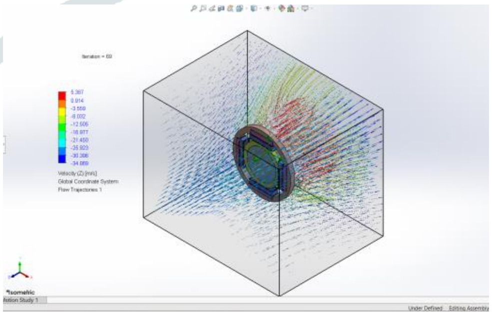


Fig 15: Velocity Flow Trajectories

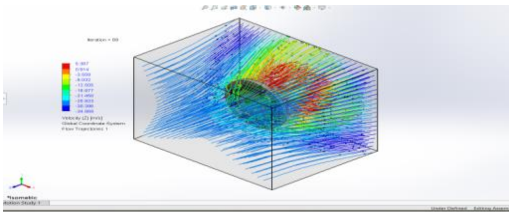


Fig 16: Air Flow Velocity

III. RESULTS AND CONCLUSSIONS

The CFD analysis of Hybrid Magnetic Bearings (HMB) using SolidWorks Flow Simulation revealed that HMBs exhibit lower efficiency compared to traditional bearings due to distinct frictional characteristics and fluid flow behaviour. Detailed modelling and fluid flow conditions assessment showed significant differences in pressure distribution around the HMB, contributing to its unique performance. The flow analysis provided critical insights into the areas where fluid dynamics impact HMB efficiency, highlighting opportunities for optimization and design improvements to enhance performance.

Performance metrics of hybrid magnetic bearings (HMBs) for high-speed spindles show notable variances from those of conventional systems. An angular velocity of 104.7 rad/s and an input power of 200 W are obtained when the frictional force is 1 Nm at a rotating speed of 1000 rpm. At this speed, the efficiency is 47.64%, resulting in a 104.72 W power loss.

The frictional torque drops sharply to 0.0003 Nm when the rotating speed is increased to 30,000 rpm. This leads to an angular velocity of 1700 rad/s, but with a much smaller input power need of 20.67 W. The HMB system's efficiency increases significantly to 98.9% at this high speed, with a negligible 0.2278 W power loss.

These findings demonstrate the superior performance of HMBs at high rotational speeds, showing a notable decrease in frictional torque in addition to improved efficiency and decreased power loss. This suggests that high-speed applications benefit greatly from the dependable, low-friction assistance that HMBs offer at a low energy consumption.

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