iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: IV Month of publication: April 2026

DOI: https://doi.org/10.22214/ijraset.2026.80253

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

Contactless Bearing Technologies for Advanced Rotor Systems: Dynamic Performance of Active and Passive Magnetic Bearings

Sushil Sharma
Condition Monitoring- Manager, Technical Services Department, Hindalco Mahan Singrauli,486886, India

Abstract: Magnetic bearings are advanced electromechanical support systems that enable contact-free levitation and stabilization of rotating shafts through controlled magnetic forces. By eliminating mechanical contact, friction, and lubrication, magnetic bearings offer high-speed capability, low wear, and improved operational reliability, making them well suited for rotor dynamic applications. Based on their force generation and control mechanisms, magnetic bearings are classified into active magnetic bearings and passive magnetic bearings. Active Magnetic Bearings employ electromagnets, position sensors, digital controllers, and power amplifiers to form a closed-loop control system that continuously regulates rotor position. This architecture provides tunable stiffness and damping, enables active vibration suppression, and supports stable operation beyond critical speeds, leading to widespread adoption in high-speed turbomachinery, compressors, pumps, flywheels, and vacuum systems. Passive magnetic bearings rely on permanent magnetic forces to achieve contactless rotor support without external power input. While Passive magnetic bearings offer simplicity, zero operating power consumption, and suitability for clean or harsh environments, their lack of inherent damping and stability limitations restrict their standalone use in rotor dynamic systems. Consequently, hybrid bearing configurations combining passive load support with active stabilization are frequently employed. This paper presents an overview and comparative assessment of active and passive magnetic bearings for rotor dynamic applications.
Keywords: Active magnetic bearing, passive magnetic bearing, electromechanical support, position sensor, digital controller, hybrid bearing.

I. INTRODUCTION

Magnetic Bearings are electromechanical systems that provide contact-free support of rotating shafts by means of controlled electromagnetic forces. These systems eliminate friction and lubrication requirements, thereby facilitating high-speed and high-reliability operation. These are classified in active magnetic bearing and passive magnetic bearings, Active magnetic bearings (AMBs) enable high-speed rotor operation (up to 180 m/s+), featuring non-contact, oil-free levitation for superior reliability, zero wear, and active vibration damping. They utilize electromagnets, sensors, and controllers to maintain precise air gaps, ideal for high-speed motors, turbochargers, and vacuum systems, allowing tunable stiffness While Passive magnetic bearings for rotor dynamics also enable contactless, oil-free, and low-maintenance suspension for high-speed machinery like flywheels and turbomachinery. Using permanent magnets in repulsion or attraction, they offer zero power consumption but typically lack inherent damping. They require supplementary damping systems to pass through resonance frequencies. Active Magnetic Bearings incorporate a closed-loop control architecture consisting of position sensors, digital controllers, and power amplifiers to actively regulate rotor displacement and suppress dynamic instabilities. in which electromagnetic forces are used to levitate the rotor without physical contact. This contactless operation eliminates frictional losses and lubrication-related issues, enabling high-speed performance and extended system lifespan. The rotor position is actively controlled using a feedback system comprising sensors, The application of Active Magnetic Bearings (in turbomachinery offers significant operational advantages. High-speed turbocompressors, pumps, and turbines employ AMBs to minimize mechanical contact and friction, thereby enhancing overall efficiency and extending machine service life. In such systems, the rotor shaft is suspended in an electromagnetic field within the bearing housing, enabling contactless operation. This levitation is achieved through a closed-loop control strategy, where digital controllers regulate the electromagnetic forces acting on the shaft based on vibration signals measured by displacement sensors and the associated system transfer functions.
The use of active magnetic bearings has been on the rise, owing to this system's increased efficiency, its high-speed capabilities and low maintenance needs.

The applications of active magnetic bearings are wide, and have opened many doors in different areas. In the field of thermal engineering, their use has translated into the development of highly-efficient, large-capacity heat pumps and dry condenser chillers, thus facilitating the development of increasingly sophisticated equipment. In the current context, enhancing efficiency and reducing maintenance needs remain two key interests when developing any piece of equipment. It's precisely in this context where active magnetic bearings stand out as an alternative to conventional mechanical bearings. Let's see what they are exactly and how they're improving efficiency across a wide range of equipment.

A. Active Magnetic Bearing Operating Principle

It uses contactless electromagnetic forces to levitate and position a rotating shaft (rotor) within a stationary housing (stator). A closed-loop control system—comprising position sensors, a controller, and power amplifiers—constantly monitors the shaft's position thousands of times per second and adjusts current to electromagnets to maintain optimal, This magnetic bearing is an oil-free bearing system that uses electromagnetic forces to maintain relative position of a rotating assembly (rotor) to a stationary component (stator). An advanced electronic control system adjusts these electromagnetic forces in response to forces generated from machine operation as shown in figure-1

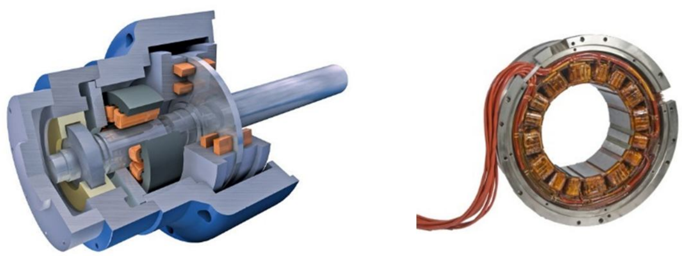


Figure-1: Active Magnetic Bearing overview

Electromagnetic Suspension: The bearing uses electromagnetic force to counteract gravity and operational loads, holding the rotor in a precise, non-contact state.

Active Feedback Loop: Position sensors detect the exact location of the shaft, sending this information to a controller. The controller calculates necessary adjustments, and power amplifiers adjust the current in the electromagnet coils instantaneously to correct any movement (often 10,000+ times per second).

Active vs. Passive: Unlike permanent magnets, AMBs actively manage forces to provide stability and damping, preventing the inherent instability found in purely passive systems.

Components of an Active magnetic bearing system

- Rotor (Shaft): A ferromagnetic component that acts as the target for the magnetic force.
- Stator (Electromagnets): Coils wound around magnetic cores located on the stator (stationary part).
- Position Sensors: Measure the position of the rotor relative to the center, crucial for the feedback loop.
- Controller: A processor that determines the required current to maintain stability based on sensor data.
- Power Amplifier: Provides electricity to the electromagnets to adjust magnetic fields instantly.

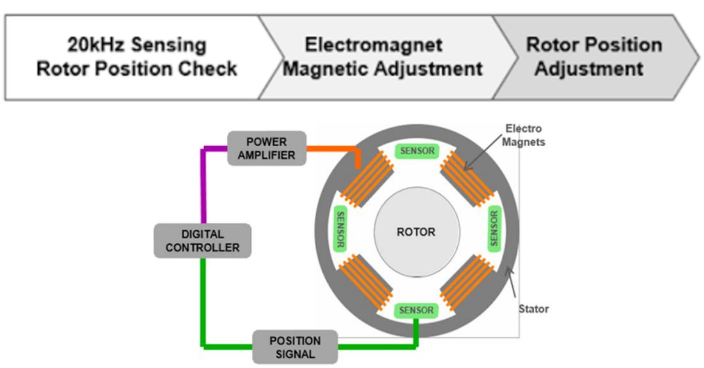


Figure-2: Active Magnetic Bearing control circuit

An active magnetic bearing (AMB) (figure-2) stator consists of laminated soft magnetic material, electromagnetic coils, a housing, and integrated position sensors. These components generate magnetic flux to levitate the rotor, with laminated iron cores (stacks) typically holding windings, while the stator structure maintains a small gap for non-contact operation

B. The benefits of an active magnetic bearing system

Active magnetic bearings present a series of advantages which have led professional and regulatory bodies (such as the U.S. Department of the Navy) to recommend their implementation. In this particular case study, the organization corroborated that magnetic bearing control can perform more efficiently than conventional mechanical bearings, particularly during partial load conditions. Research detected an average of 49% in power savings and a 6.4 years average ROI. The reason behind the benefits of active magnetic bearings is their no-contact working principle between rotating and stationary parts, as opposed to conventional bearings. In fact, the latter rely on mechanical contact to support the load and reduce friction and must use oil as a lubricant, becoming the cause of wear in the equipment. As such, the magnetic bearing provides several advantages for the high lift oil free compressor compared with the traditional oil lubed compressor with gear box:

Frictionless performance: there's a lack of physical contact between the moving parts and thus, virtually no friction. This working principle allows for a higher heat transfer efficiency of the chiller, reducing energy losses due to friction.

Direct drive motor compressor, no gearbox and less moving parts.

No oil pump required, no oil pump nor oil heater power consumption.

No oil injection piping, no oil cooler, no oil filters, less possible leaking points (joints).

Low maintenance: because of this lack of mechanical contact and an oil free functioning, wear of parts also diminishes, resulting in reduced maintenance requirements and a longer service life.

Minimum noise and vibration: the lack of physical contact between the parts results in less noise and vibrations

All in all, the implementation of active magnetic bearings in centrifugal chillers results in higher efficiencies and less maintenance needs, two crucial aspects that define priorities in the current context.

C. Passive Magnetic Bearings

Passive magnetic bearings (PMB) achieve contact-free levitation of an object by permanent magnetic forces, either by two magnets attracting or repulsing each other. Depending on the configuration, stabilization in radial, axial and tilt direction are possible.

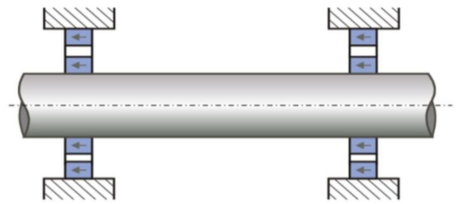


Figure-3: Passive Magnetic Bearing repulsive forces stabilize radial shaft motion

It is, however, not possible, to stabilized all degrees of freedom of a body by passive magnetic levitation, alone. This has been shown by Braunbek who interpreted the prior findings of Earnshaw on the stability conditions in force fields for magnetic levitation. Diamagnetic materials such as superconductors are explicitly not considered in this theorem. A very simple PMB design consists of permanent magnetic rings on both, the rotating shaft and the stator, which stabilize the radial movement by repulsive forces (figure-3).

Different configurations of attractive or repulsive permanent magnets (figure-4) are possible in classic PMBs. The table shows common arrangements with one or two ring magnets. Stacking the magnets or magnet pairs can be used to increase the bearing forces and also the stiffness

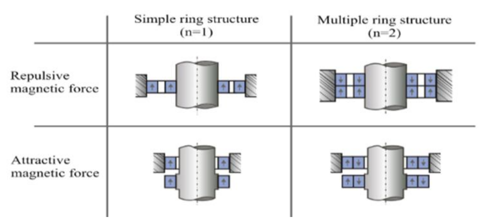


Figure-4: attractive and repulsive magnetic force

Using disk-shaped rotors allows stabilizing more than one degree of freedom with only one permanent magnet. In the example shown here figure-5, both the axial and tilting motion of the inner rotor are stabilized passively.

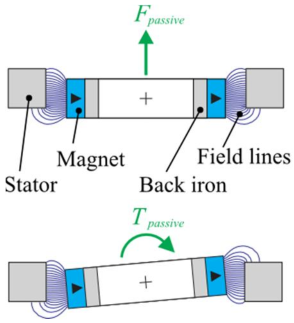


Figure-5: passive force in axial and tilting motion

PMBs are cheap, small, and mechanically simple, since they require no active components such as actuators, coils or power electronics. Their stiffness values are determined by the configuration and the material properties. Their biggest disadvantage is the lack of damping: The PMB itself provides close to zero damping which is why, typically, additional damping measures are added. The options range from visco-elastic to electrodynamic or other mechanic damping elements.
The figure-6 of a magnetically levitated rotor shows a magnetic bearing concept with relatively low constructive complexity. The radial and tilt stabilization are achieved by two passive magnetic bearings. The active element is used to control the axial rotor position, which is unstable due to Earnshaw’s Theorem.

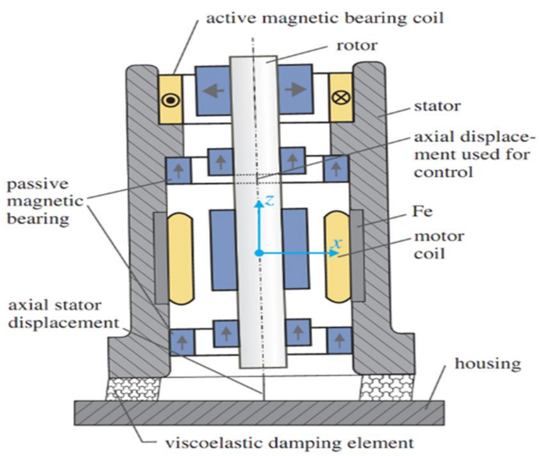


Figure-6: magnetic levitated rotor with passive magnetic bearing

Due to the lack of damping of permanent magnetic bearings, additional measures are required to gain sufficient stability against disturbances and to successfully pass resonance frequencies during run-up. For applications with a limited temperature range, one possibility is to use visco-elastic stator supports to dampen the rotor vibrations. Alternatively, eddy current dampers can be used to constrain rotor vibrations. These damping measures demand considerable modelling effort but strongly improve the system performance: The vibrations caused by unbalance, magnetic tolerances or external excitations can be suppressed.

D. Advantages of Passive Magnetic Bearings

No Wear and Maintenance-Free: As contactless devices, PMBs eliminate surface friction and wear, leading to much longer operating lives compared to traditional bearings.
Lubricant-Free: Since they do not require oil or grease, they are ideal for clean environments, vacuum systems, and industries where contamination is a concern.
Low Power Consumption: Because they rely on permanent magnets rather than electromagnets (as in active magnetic bearings), PMBs require little to no power to operate.
High-Speed Capability: The lack of physical contact allows for very high rotational speeds.

Simple and Robust Design: The design is straightforward, often using simple, stacked permanent magnet rings, which translates to high reliability and lower cost compared to Active Magnetic Bearings.
Reduced Noise and Vibration: Their design can reduce vibration transmission to stationary components, providing smoother operation.
Environmental Compatibility: They are suited for harsh, inaccessible, or remote environments.

E. Active and Passive Magnetic Bearings for Rotor Dynamic Applications

Magnetic bearings have emerged as an advanced support technology in rotor dynamic systems due to their contactless operation, controllable stiffness, and reduced mechanical losses. Depending on the method of force generation and control, magnetic bearings are broadly classified as Active Magnetic Bearings (AMBs) and Passive Magnetic Bearings (PMBs). Both types have been investigated for rotor dynamic applications, either independently or in combined configurations.
Active Magnetic Bearings are widely used in rotor dynamic applications where precise control and stability are essential. AMBs employ electromagnets to generate suspension forces, which are actively regulated through a closed-loop control system. Rotor position is continuously monitored using displacement sensors, and corrective electromagnetic forces are applied via power amplifiers and digital controllers.

F. From a Rotor dynamics perspective, AMBs offer several key advantages

Active vibration control: Rotor vibrations caused by unbalance, misalignment, or transient disturbances can be effectively suppressed.
Tunable stiffness and damping: Dynamic properties of the bearing can be adjusted in real time to improve system stability.
High-speed capability: AMBs enable stable operation beyond critical speeds without mechanical wear.
Enhanced diagnostic capability: Integrated sensing allows continuous condition monitoring of the rotor system.
Due to these properties, AMBs are extensively applied in high-speed turbomachinery, compressors, turbines, flywheels, and energy storage systems, where rotor dynamic performance strongly influences reliability and efficiency.
Passive Magnetic Bearings utilize permanent magnets or superconducting materials to provide levitation forces without external power input or active control. Their contactless and energy-efficient nature makes PMBs attractive for certain rotor dynamic applications; however, they exhibit inherent limitations.
Key characteristics of PMBs include: Absence of active damping, limiting their ability to suppress vibration and dynamic instabilities. Stability constraints, as purely passive magnetic systems cannot achieve stable equilibrium in all directions without supplementary mechanisms.
Limited adaptability, since PMBs cannot respond dynamically to variable operating loads or disturbances.

G. Hybrid Use in Rotor Dynamic Systems

To leverage the advantages of both bearing types, hybrid magnetic bearing systems are frequently adopted in rotor dynamic applications. In such systems:
Passive magnets provide static load support, reducing power consumption.
Active magnetic bearings supply dynamic stabilization and vibration control.
Hybrid configurations are particularly beneficial in applications requiring improved energy efficiency while maintaining robust rotor dynamic stability.

H. Magnetic bearings vs Hydrodynamic bearings vs Rolling bearings

Feature / Parameter	Hydrodynamic Bearings	Magnetic Bearings (Active / Passive)	Rolling-Element Bearings
Load Support Mechanism	Pressure generated by lubricant film	Electromagnetic forces (active) or permanent magnets (passive)	Mechanical contact between rolling elements and races

Contact Between Rotor & Stator	No contact during steady operation (oil film)	No physical contact (fully contactless)	Direct mechanical contact
Lubrication Requirement	Required (oil or fluid)	Not required (oil-free)	Required (grease or oil)
Friction Losses	Low at rated speed, high at startup/shutdown	Very low	Moderate due to rolling contact
Operating Speed Capability	Very high (suitable for turbomachinery)	Extremely high	Limited by fatigue and heat generation
Damping Characteristics	High inherent damping	Low inherent damping (active damping added via control)	Low damping
Stiffness	Speed-dependent	Actively tunable (AMBs) / fixed (PMBs)	Fixed
Vibration Control	Passive damping only	Excellent (active vibration suppression)	Limited vibration control
Stability at High Speeds	Generally stable, may suffer from oil whirl/whip	Highly stable with proper control	Reduced stability at very high speeds
Maintenance Requirement	High (lubrication system, seals, oil quality)	Low (no wear surfaces)	Moderate (fatigue wear, lubrication)
Wear and Fatigue	Minimal during normal operation	Negligible	Significant over time
Startup & Shutdown Behaviour	Metal-to-metal contact possible	Fully contactless	Wear occurs
Thermal Sensitivity	Affected by oil viscosity and temperature	Sensitive to electronics and power loss	Sensitive to heat buildup

II. CONCLUSIONS

Magnetic bearings have demonstrated significant potential as an advanced support technology for rotor dynamic applications, owing to their contact-free operation, elimination of lubrication, and capability for high-speed and high-reliability performance. This paper examined the fundamental principles, characteristics, and applicability of Active Magnetic Bearings (AMBs) and Passive Magnetic Bearings (PMBs), with particular emphasis on their impact on rotor dynamic behaviour.

Active Magnetic Bearings, through closed-loop control employing sensors, digital controllers, and power amplifiers, provide tunable stiffness and damping, active vibration suppression, and stable operation across critical speeds. These features make AMBs particularly suitable for high-speed turbomachinery, compressors, pumps, and energy-efficient thermal systems, where improved efficiency and reduced maintenance are critical. In contrast, Passive Magnetic Bearings offer simplicity, zero operating power consumption, and maintenance-free operation; however, their lack of inherent damping and stability constraints limit their standalone use in practical rotor dynamic systems. The study further highlights that hybrid magnetic bearing arrangements, combining passive magnetic load support with active control, represent an effective compromise by reducing power consumption while maintaining dynamic stability. Compared with conventional hydrodynamic and rolling-element bearings, magnetic bearings provide superior performance in applications demanding high speed, low vibration, and minimal maintenance.

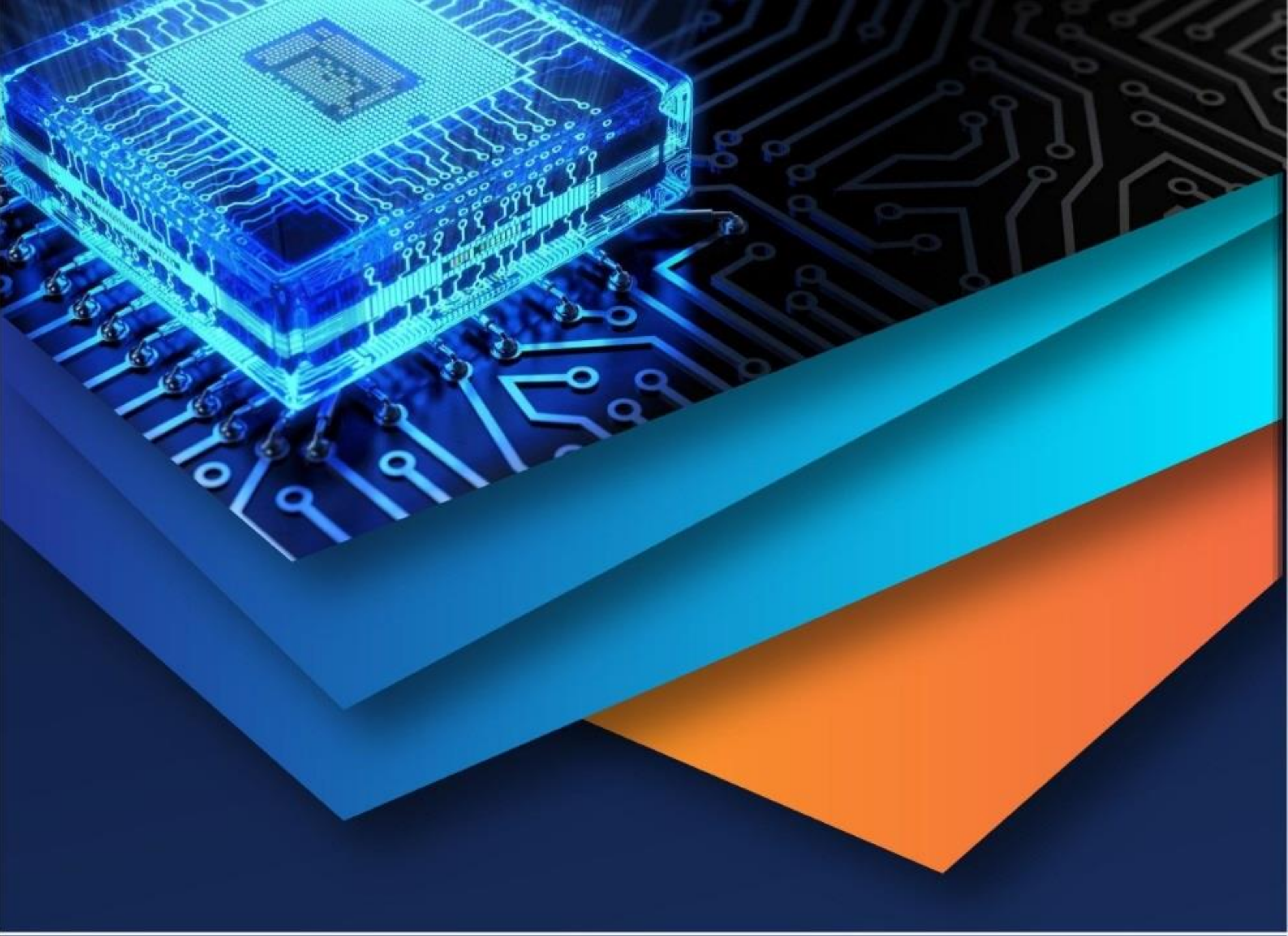
Overall, magnetic bearing technology—particularly AMBs and hybrid configurations—emerges as a promising solution for next-generation rotor systems, supporting the ongoing demand for higher efficiency, operational flexibility, and reliability in rotating machinery.

III. ACKNOWLEDGE

I would like to express my sincere gratitude to my seniors, whose guidance, encouragement, and insightful feedback were invaluable at every stage of this work. Special appreciation goes to my colleagues and peers for their constant support, lively discussions, and collaborative spirit, which greatly enriched this study. Finally, I am profoundly thankful to my family and friends for their patience, understanding, and unwavering encouragement throughout this research.

REFERENCES

[1] Araner blogs for advanced bearings system for rotor dynamic application in industry applications.
[2] Magnetic bearings catalogue literature for industry applications purpose.
[3] Waukesha bearings literature and blogs for advance bearing system in rotor dynamic applications.
[4] Rotor dynamic machinery book by Prof Vance.



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY