# Study of Active Magnetic Bearing

**Shubham Naikwad**

*Abstract*— **The use of bearings is essential to all types of machines, in that they provide the function of supporting another piece or component in a desired position. Two major types include radial and axial bearings. A further classification can be made into active and passive bearings, which is addressed in this paper. More than thirty years of research and application have led to active magnetic bearings (AMB). Active magnetic bearing can support a shaft, rotor without any physical contact and enables the user to precisely control shaft or rotor position and vibration as a function of time and other parameters. This frictionless and programmable features have made AMB suitable to meeting the demand for higher speed, higher efficiency and reliability of rotating machinery in many industrial application including flywheel energy storage, momentum wheels, turbo machineries, precision machineries, vacuum pumps, medical devices. Other features of AMB, such as the absence of contamination by lubrication or mechanical wear, low energy consumption and low maintenance cost are prevailing now. This paper reviews the components and working principles of AMB, which requires the basic understanding of rotor dynamics, electromagnetism, power electronics and control theories. AMB is typical mechatronics product. Furthermore, the use AMB as key to smart machinery allows the integration of machine into control of a whole production process and to manage safety and maintenance issues.**

*Index Terms*— **Control theories, Magnetic bearing, Mechatronics, Rotor dynamics**

## I. INTRODUCTION

Active magnetic bearings are replacing oil-lubricated bearings in many applications. The benefits of using magnetic bearings in rotating machinery include higher reliability with little or no maintenance, reduced frictional losses, no contaminating or flammable lubricants, reduced machine vibration, and improved health monitoring and diagnostics. However, despite these advantages, the application of magnetic bearings has been limited in the past by the large size of the magnetic bearings, the complexity of integrating the magnetic bearings into the machine, the need for a large external control system, and the high cost. Recent advances in magnetic bearing technology, including miniaturization, simplicity and integration have overcome many of these limitations. As a result, magnetic bearings are replacing oil-lubricated bearings for many new types of machines in a variety of industries.

Active magnetic bearing system levitates the rotating shaft and maintains it in position by applying controlled electromagnetic forces on the rotor in radial and axial directions. The active magnetic bearing is the principle which is actually used most often among the magnetic suspensions. A sensor measures the displacement of the rotor from its reference position, a microcontroller as a controller derives a control signal from the measures and gives signal to a power amplifier into a control current, and the control current generates the magnetic forces within the actuating magnet in such a way that the rotor remains in its hovering position. This enables very high rotational speed to be realized. A magnetic bearing is free of lubricant, which avoids servicing and also enables use in clean room environment. Maintenance is also decreased due to absence of surface wear, so that as long as the control system functions as intended, there could be no maintenance. One major disadvantage to using magnetic bearings is their complexity. A very knowledgeable person in the field is generally required to design and implement a successful system. Because of the large amount of effort and time required for development and the increase in the number of components, compared to a traditional bearing, the initial costs are much higher. However, depending on the application, the return on investment for these initial costs could be relatively short for a system, for example, that runs with a much higher efficiency due to the lack of bearing friction resistance.[1]

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## II. GLANCE OF HISTORY

The table below lists several early patents for active magnetic bearings suspension can be found out but are excluded here because they consist of assemblies of permanent magnets of problematic Earnshaw’s Theorem.

**Table 1** : Early U. S. Patents in AMB [2]

| Inventor | Year | Patent no. | Title |
|---|---|---|---|
| Beams Holmes | 1941 | 2,256,937 | Suspension of Rotatable bodies |
| Beams | 1954 | 2,691,306 | Magnetically supported Rotated bodies. |
| Beams | 1962 | 3,041,482 | Apparatus for rotating freely suspended body |
| Beams | 1965 | 3,196,694 | Magnetic suspension bodies |
| Wolf | 1967 | 3,316,032 | Poly phase magnetic suspension transformer |
| Lyman | 1971 | 3,565,495 | Magnetic suspension apparatus |
| Habermann | 1973 | 3,731,984 | Magnetic bearing block device for supporting a vertical shaft adapted for rotating at high speed. |
| Habermann, Brunet | 1977 | 4,012,083 | Magnetic bearings |
| Habermann, Brunet, Leclere | 1978 | 4,114,960 | Radial displacement detector device for a magnetic bearing |
| Meeks, Crawford R | 1992 | 5,111,102 | Magnetic bearing structure |

## III. PRINCIPLE AND OPERATION OF AMB

Active magnetic bearing (AMB) works on the electromagnetic suspension principles. Electromagnetic suspension is the magnetic levitation of an object achieved by constantly altering the strength of a magnetic field produced by electromagnets using a feedback loop. A charged body cannot rest in stable equilibrium when placed in a pure electrostatic field or magneto static field (Earnshaw's theorem) [3]-[4]. In these kinds of fields an unstable equilibrium condition may exists, also static fields may provide to fail the stability, electromagnet suspension works by continually altering the current sent to electromagnets to change the strength of the magnetic field and allows a suitable levitation to occur [5]. In EMS a feedback loop which continuously adjusts one or more electromagnets to correct the objects motion is used to cancel the instability. A set of power amplifiers which supply current to the electromagnets, a controller and gap sensors with associated electronics to provide the feedback required to control the position of the rotor within the gap [6]. The power amplifier supplies equal bias current to two pairs of electromagnets on opposite sides of the rotor. Then constant tug-of-war is mediated by the controller which offsets the bias current by equal and opposite perturbations of current as the rotor deviates from its center position. The gap is monitored by a current sensors and sense in a differential mode. The power amplifiers operation can be achieved by Pulse Width Modulation (PWM) technique. The controller is usually a Proportional Integral Derivative (PID) controller [7].

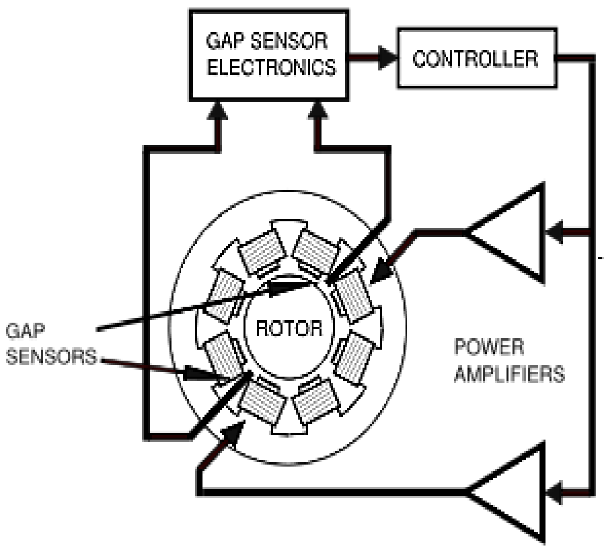


**Figure 1 :-** Principle operation of bearing [2]

## IV. WORKING OF ACTIVE MAGNETIC BEARING

A typical AMB is made up of the following elements:

- Stator
- Rotor
- Sensors
- Electromagnets

AMB can be configured as either radial or thrust bearing. These elements are shown in the diagram below.

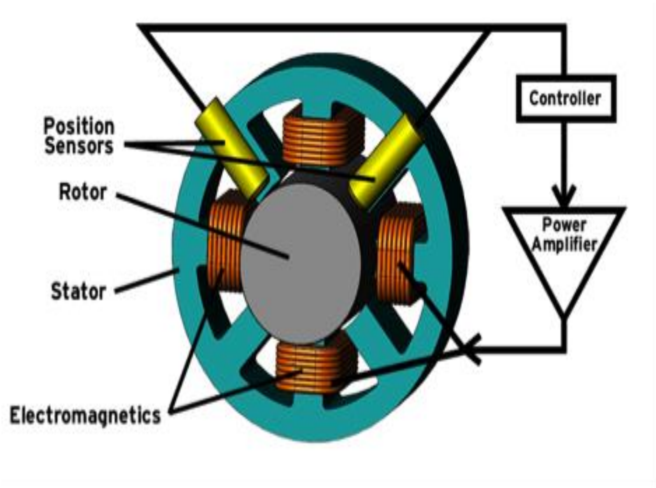


**Figure 2:-** Elements of AMB [8]

The power amplifiers supply equal bias current to two pairs of electromagnets on opposite sides of a rotor. The controller offsets the required bias current by equal but opposite perturbations of current as the rotor deviates by a small amount from its center position. The gap sensors are usually inductive in nature and continuously sensing the gap between rotor and the bearing. The sensor measures the position of the body. The control electronics then calculates the right current to suspend the ball.

This current is set by the amplifier. The resulting force is within limits proportional to the square of the current and inversely proportional to the square of the position.

$$F = (I/X)\text{^}2$$

Controller uses microprocessor to allow the whole system function in a stable manner.

Typical active magnetic bearing system components:

- Stator
- Rotor
- 2 Radial Magnetic Bearings
- 1 Thrust (Axial) Magnetic Bearing
- Controller
- Power Supply
- UPS (Uninterruptable Power Supply)

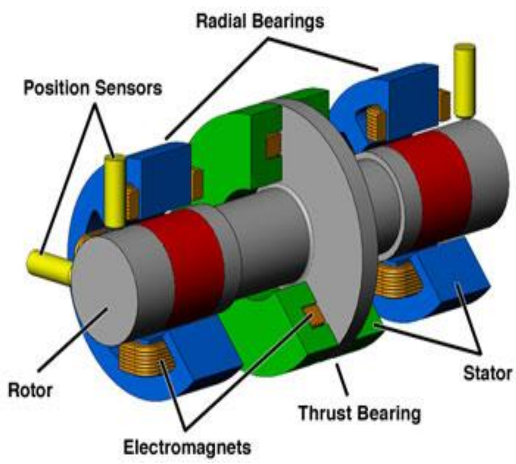


**Figure 3:-** Active magnetic bearing system components [9]

**Getting information from the AMB system (Health or Condition Monitoring):**

Synchrony has dedicated many years of research and development into creating and supplying its proprietary machine health monitoring software and condition monitoring. Much of the ability to miniaturize and simplify physical attributes of magnetic bearing systems is due to Synchrony's technological breakthroughs in controls software.

Magnetic bearings in industrial applications offer greater reliability than ever because of remote bearing monitoring capabilities that let users recognize and head off potential trouble before it even starts. That helps set Synchrony® products apart from earlier generations of magnetic bearings. Superior bearing vibration monitoring allows continuous system performance feedback to help you get the most from magnetic bearings capabilities, while keeping costs down.

Health monitoring of magnetic bearings previously required large, expensive hardware. Synchrony builds sensors right into radial and thrust bearings, and each "smart" bearing comes with its own IP address, so information can be fed into an HMI that's easy to use and configurable to each operator's needs. Regardless of your location.[9]

**Bearing monitoring capabilities:**

- Monitor trends and changes in operating conditions
- Predict and schedule pre-emptive maintenance shutdowns
- Maximize uptime and minimize component damage
- Ensure maximum efficiency

## V. DESIGN, COST AND PERFORMANCE ISSUE

Currently, there is still no industrial or international standard for AMB design procedures and performance requirements. The International Organization for Standardization (ISO) and International Electro technical Committee (IEC) are still preparing a draft of ISO 14839 for this purpose. The AMB ISO 14839 draft can be accessed at an internet address shown in reference [10].

There are several variations in the AMB systems configuration. These variations exist because of the need for lower hardware cost and more fault tolerant AMB systems. For example, an AMB system which is so called "self-sensing", does not require position sensors which means lower hardware cost. However, the stability margin and robustness can easily degrade. So does the AMB system that only has 3 poles of electromagnets in each bearing.

The design of AMB systems need to consider the worst case scenario such as loss of control due to faulty hardware/software components, and due to large external disturbances such as an earthquake or other vibrations. For this purpose, auxiliary bearings are always incorporated as a back-up. The diameter of auxiliary bearings is sized such that the electromagnets are well protected during the "crash" and during power start-up and termination.

An example of hardware cost in the year of 2006 for typical AMB systems is shown in Table 2 assuming a mass production i.e. At least a thousand AMB units for a vertical rotor with mass of 250 kg, diameter about 5 cm, maximum speed about 25 thousand RPM, distance between bearings about 0.5 meter, and maximum force per axis about 250N.

**Table 2:-** AMB components cost estimate

| AMB components | Estimated cost (US Dollar) |
|---|---|
| 2 electromagnets+ position sensors | 300-500 |
| 8 PWM power amplifiers, @ 50 watt max | 400-800 |
| DSP+electronics +power supplies | 750-1500 |
| Wiring | 100-200 |
| 2 auxiliary bearings | 50-200 |
| **Total** | **1700-3200** |

It is worth noted that in some designs and applications, the total electrical loss of AMB systems may be higher than the power loss due to mechanical friction of conventional bearings. The wiring of power lines from power amplifiers to electromagnets should be made as short as possible in order to reduce electrical resistance. However, in many applications the other benefits of AMB already overcome this electrical loss such that AMB is still an attractive choice. Adaptive Vibration Control (AVC) feature in AMB systems is useful after a certain RPM. Using a gradient method to minimize cost function of influence efficient matrix, AVC can "on-the-fly" reduce or eliminate synchronous vibration due to mass unbalance. Because of its great advantage, this feature is almost always incorporated in the AMB systems.[9]

## VI. MAJOR PLAYERS IN AMB TECHNOLOGY

There have been numerous AMB manufacturers in the world [8]-[11]. The two most industrious ones are S2M in France and Revolve in Calgary, Canada. S2M has sold thousands AMB systems primary for compression systems for oil and gas production industry. Another AMB company, Synchrony focuses on "high grade" fault tolerant AMB systems that can be used by aerospace industries and future aircraft engines.

Due to the rapid progress in electronics including DSP technology, there are chances of avenues for further research in AMB. Performance improvement, cost reduction, and additional design objectives within specific applications are some of the examples. In the recent years, researchers working on magnetic bearings have been aggressively focusing in areas such as (1) studies to utilize modern control methods including multi-variable controls, robust controls, non-linear controls, and adaptive controls in order to minimize rotor vibration; (2) studies of levitating more flexible rotors; (3) studies of self-sensing magnetic bearings; (4) studies on the joint use of magnetic bearings for levitation and motor-stators for rotation; (5) hybrid passive and AMB; and (6) studies on zero-power magnetic bearings using superconductor materials. Most of the above research topics are conducted at the three most notable AMB research and academic centers in the world [12-13]: (1) Rotating Machinery and Controls Laboratory (ROMAC) at the University of Virginia, Virginia, USA; (2) The International Center for Magnetic Bearings (ICMB) at The Institute of Robotics, ETH Zurich, Switzerland; and (3) Institute for

Machine Dynamics and Measurements (MTMD), Viena University of Technology, Vienna, Austria.

## VII. APLLICATION

1. Magnetic bearings are increasingly used in industrial machines such as compressors, turbines, pumps, motors and generators
2. Magnetic bearings are commonly used in watt-hour meters by electric utilities to measure home power consumption.
3. Magnetic bearings are also used in high-precision instruments and to support equipment in a vacuum.
4. Magnetic bearings are also used to support Maglev trains in order to get low noise and smooth ride by eliminating physical contact surfaces.
5. A very interesting new application of magnetic bearings is their use in Artificial hearts.
6. Now-a-days, they are in service in such industrial applications as Electric power generation, Petroleum Refining, Machine tool operation and Natural gas pipelines.

## VIII. LIMITATION OF STUDY

Active magnetic bearing are not much used in the industries because its complexity and high cost than conventional bearing despite of AMB provides many advantages. It's a pressing need that the attempts should be made to reduce the complexity and cost of AMB by experiments and further studies on AMB. Synchrony AMB's manufacturer has been working on the same. This will helps for small scale industries to adopt the use of AMB to increase performance of machineries. For that work on the AMB components and this components can be optimize so that AMB can use as equivalent to conventional mechanical bearing.

## IX. CONCLUSION

The AMB technology has been briefly reviewed including its advantages, components, working principles, cost and performance. Some design and implementation issues have been also discussed. The authors believe that AMB systems are still relatively more expensive than conventional mechanical bearings, some studies are needed to tackle the cost and complexity issues; therefore the massive used of AMB in industries is still prohibitive despite of the many benefits offered. The AMB will still not completely replace conventional bearings in rotating machineries in the near future. However, AMB can find its place well in a limited volumes of high performance rotating machines.

## ACKNOWLEDGMENT

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