Review on Design, Optimization and Analysis of a Radial Active Magnetic Bearing for Vibration Control

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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 in to 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.*

Keywords- 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. Active 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].

II. PRINCIPLE AND OPERATION OFAMB

Active magnetic bearing (AMB) works on the electromagnetic postponement principles. Electromagnetic suspension is the magnetic levitation of an object achieved by constantly changing the strength of a magnetic field produced by electromagnets using a response loop. A exciting body cannot rest in stable equilibrium when placed in a pure electrostatic field or magneto static field (Earns haw'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 them agnetic field and all ow sasuitable 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].

There are mainly two types of loads acting on the rotor namely, the static and the dynamic. The static load include the load due to the weight of the rotor, external static loads on the rotor due to interconnectivity to other machine elements such as springs, preloads, etc. Dynamic loads includethe mass imbalance of the rotor due to eccentricity, external disturbances due to base vibrations, applied load variations on the system, impact forces due to touch down bearings, etc. A current called the bias current is supplied to cancel out the static load acting on the rotor or a set of permanent magnets are used to support the static load. But due to the negative stiffness owing to the magnetic force a small disturbance would move the rotor away from the operating position. Hence, the rotor should be brought back to the operating position by using control methods. In this regard the rotor position is sensed by a sensor and the sensor signal is given to the controller, which sends the signal to the power amplifier based on the difference of the sensor signal from the reference signal. To bring back the rotor to its original position, the actuator is supplied with an additional current demanded by the controller through the poweramplifier.

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 off sets the biascurrent 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].

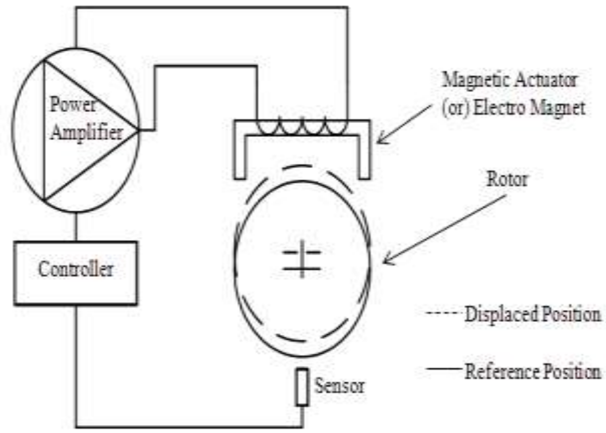

Figure 1 :- Principle operation of bearing [2]

The power amplifiers supply equal basic current to two pairs of electromagnets on contradictory sides of a rotor.

The controller offsets the necessary 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 incessantly sensing the gap between roto rand the bearing .The sensor measures the position of the body. The control electronics then calculates the right current to hang up the ball.

III. COMPOSITE MATERIALS

When two materials having different properties are combined together at macroscopic level, it results into a composite material. The mechanical properties of the composite materials are totally different from their essential materials and also results in a superior one. Both materials are differing in their chemical composition and its properties. The resultant composite material is high in strength and other mechanical properties. Two types of composite materials are givens

- Particulate Composite.
- Fiber Reinforced Composite,

When particles of different sizes and shapes are mixed in a random way with the matrix, Particulate composites are formed. Mika flakes reinforced with glass, aluminum particles in polyurethane rubber are some examples of Particulate Composites. Fiber reinforced composite material consist of fibers of significant strength and stiffness imbedded in a matrix. Equally fibers and matrix maintain their physical and chemical properties. Fiber reinforced composite having continuous fibers are more efficient. FRP can be classified into four categories according to matrix used such as: polymer matrix composites, metal matrix composites, ceramic matrix composite and carbon/carbon composites.

IV. LAMINA AND LAMINATES

Lamina is also called ply and it shows one layer of composite material. This is the essential block of the composite materials. Unidirectional fiber reinforced materials show good properties like high strength and modulus but particularly in the direction of the fibers. On the other hand the properties are very poor in the direction other than the direction transverse to the fibers. Bonding between fiber and matrix is also essential because a good bonding results in higher strength of the composite structure. Discontinuous laminates have reduced mechanical properties than continuous laminates.

Laminate is simply a collection of different laminas or ply. It is done to achieve desired stiffness and mechanical properties of the materials. The sequence of orientation of different ply in a single composite material is termed as stacking sequence. The layers are attached with the same matrix material as that in a lamina.

Different types of laminates are classified as follows

- Symmetric Laminate
- Asymmetric Laminate
- Balanced Laminate
- Quasi isotropic Laminate

V. VIBRATION OF COMPOSITE SHAFT

When a body goes to and fro motion with respect to its equilibrium position, it is said to be vibrating. Vibration is an important phenomenon in engineering and should be checked in order to recover stability. Vibration can be classified as

- Free Vibration
- Forced Vibration
- Damped Vibration

When a body is vibrating without any support of external agency, it is termed as free vibration. For example, if a spring- mass system is giving an external force initially and allowed to vibrate, it gradually comes to equilibrium position after some vibration. This is an ideal case of free vibration. On the other hand if the same system is allowed to vibrate in to and fro motion and a constant external force is useful regularly to keep the system in vibration, it is said to be forced vibration. Over again if a damper like dashpot is used in the system in addition to spring, it makes the system to slow down its vibration gradually as dashpot provides friction. The use of damper in this way results in a damped vibration.

VI ACTIVE VIBRATION CONTROL TECHNIQUES

When the vibration of rotor exceeds its limit, there is a great need to check its vibration and bring the system stability. Active control techniques are commonly used for this purpose. It has a lot of advantages over other methods like better control quick action and compact view.
Some of the active vibration control can be categorized as follows

PD Control Action

- LQR Control Action
- PID Control Action
- Proportional Control Action
- Derivative Control Action

Proportional and derivative controllers stand used in the PD control technique. The stability and overshoot complications that arise when a proportional controller is used at high calculation can be completed by addition a period proportional to the time-derivative of the error signal.

We need to operate a dynamical system at a very minimal cost. The case where the system dynamics are described by a set of differential equations which are linear and a quadratic function is used to describe the cost then it is called the LQ problem. The solution is obtained by the Linear Quadratic Regulator (LQR) which is a response controller.

VII. ADVANTAGES AND APPLICATIONS OF AMBS

The different advantages mentioned are , AMBs can be applied in vacuum without any problem of lubrication pressure and vapors’ generation, Oil free and no contamination, Increase of natural frequency due to double end free axis, Increase allowable unbalance due to non-contact support, and Rotation of the rotor around the principle axis of inertia by automatically balancing the system.

VIII. 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.

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