Project report on magnetic bearing technology engineering essay

Magnetic Bearing Technology has many applications in industries. It is expensive but has many other benefits. No other bearing can work in vacuum, which is the most important application of magnetic bearing technology.

In order to beat the limitations of conventional ball bearings, Active Magnetic bearings were introduced in engineering. Only the magnetic bearings are able to work in vacuum as compared to conventional ball bearings. As there is no contact between bearing and rotor, there is no wear. That is why there is no need for lubrication in the Magnetic bearing system which helps to design the rotors running at very high speed.

The introduction of Active Magnetic Bearing system in Engineering as a very valuable machine element helps to solve the rotor bearing problems. Just because of exclusive features of Active Magnetic Bearing System, it is possible to permit novel design approaches for rotating machinery. Most of the basic can be limitations of Active Magnetic Bearing system can be overcome. In that way it possible to extend the working ranges of the system.

Magnetic Bearing is consists of electronic elements such as sensors, power amplifiers, a microprocessor. The heart of the active magnetic bearing system is the software. The ability of sensing, flow of the information from the microprocessor and actuation makes the system powerful as compared to conventional bearings.

The major areas of application of magnetic bearings are rotary machinery, electric motors, flywheels, equipments where accuracy is of prime importance, space applications, vacuum applications etc. Industrial applications of Magnetic Bearing system is increasing day by day.

1. 2 Principle of Magnetic Bearing

The Main principle of the active magnetic bearing is generating contact free magnetic field forces by controlling the dynamics of an electromagnet. The main components of a simple magnetic bearing are shown in the figure below.

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The parts and their function are described below.

The Sensor finds out the position of the rotor from its actual position.

The Microprocessor gives a command signal from the result given by the sensor

Then Power amplifier transfers the command signal into a control current.

The control current produces a magnetic field in the magnets. This produces magnetic forces in such a way that the rotor remains in its suspended position. The stability of the rotor in suspended position depends on the control current and stiffness of the system.

1. 3 Classification of Magnetic bearings

The classification of the Active magnetic bearings is based on the two types of forces acting on it. They are reluctance force and Lorentz force.

The reluctance force f is obtained from the principle of virtual work.

$f = \partial W/\partial s$ ——————————————————-1. 1

Where W= field energy

S= Virtual displacement of the suspended body.

The direction of the force is perpendicular to the surface of different materials.

The Lorentz force F is obtained from the basic law

$F = Q (E + v*B)$ ——————————————————–1. 2

Where Q= electric charge

E= electric field

v= velocity

B= magnetic flux density

The energy density E is very is very smaller than the energy density of feasible magnetic fields. Therefore it can be neglected.

The product Qv is replaced by the current i, leading to the well known term

$F = i*B$ ——————————————————1. 4

Active magnetic bearings are classified as below.

Reluctance Force

Acts Perpendicular to Surface of Materials of Differing Permeability

Ferromagnetic

Larger forces

Classical active magnetic bearing

Tuned LC bearings low damping

Permanent magnet stationary configuration unstable

Diamagnetic

Very small forces

Meissner-Ochsenfeld

Larger forces possible through super conduction

Lorentz Force

Acts perpendicular to the flux lines (electrodynamics devices)

Permanent magnetic field

Induced current

Levitation only at high velocity low efficiency or super conductor (normal force)

AC current

Induced current

AC bearing, High losses, low damping (normal force)

Combination of induction motor and AMB self bearing motor

(Tangential force)

Controlled current Permanent magnetic field

Combination of synchronous motor and AMB self bearing motor (Tangential force)

1. 4 Characteristics of Active Magnetic bearing system

The main characteristics of AMB are as per the following.

The main characteristics of no contact with the rotor during the operation and zero lubrication and wear permits the use of magnetic bearings in vacuum systems, in clean rooms, or for the transport of aggressive or very pure media, and at high temperatures.

The gap between rotor and bearing usually a few tenths of a millimeter. But for specific applications it can be as large as 20 mm. In this case the bearing size becomes very large. Also it will be expensive.

Usually the rotor in the Active magnetic bearing system runs at very high speeds. Only the limitation against the high speed of the rotor is strength of the rotor material. This offers to design the new machines with higher power concentration.

The Losses in the Active magnetic bearing system are very low. The typical comparison shows that the losses are 5 to 20 times lower than the conventional bearings. As the losses are lowered the operating cost of the system also lowered.

The specific load capacity of the bearing depends on the type of ferromagnetic material and the design of the bearing magnet.

The dynamics of the contact-free suspension depends mainly on the control command. The control is given by a microprocessor. This makes the design which makes the design very adaptable. So, it is possible to adapt the stiffness and the damping, within physical limits.

Additional bearings are required which may ball or journal bearings. These bearings are not in contact with the rotor during the normal operation. During overload or malfunction of the Active Magnetic Bearing they have to operate for a very short time. They keep the spinning rotor from touching the housing until the rotor comes to rest or until the AMB regains control of the rotor.

The control features of Active magnetic bearing system are the unbalance compensation and the force-free rotation are control features. AMB measures and identifies the vibrations due to residual unbalance. This signal is used to generate counteracting bearing forces such that the rotor runs force free.

The precision, with which the state of the rotor can be controlled, is mainly determined by the quality of the measurement signal within the control loop.

Diagnostics are readily performed and the same information can be used to check operating conditions and performance.

The Active Magnetic Bearing has the ability to be a key element in a smart machine. The AMB can make use of its measured state information in order to optimize the operation of the whole machine. It contributes to the overall process control, and supports the safety and reliability management.

The lower maintenance costs and higher life time of an AMB have been demonstrated under severe conditions. They are due to the lack of mechanical wear.

2. DESIGN PROCEDURES

2. 1 Design of active magnetic bearing system

Active magnetic bearings are consisting of electromagnets, power amplifiers, contact free position sensors and an electrical control system. The control system gets the signal from the position sensors to find out the signal to be sent to the amplifiers. The amplifiers runs current in the electromagnet coils to create magnetic forces which act on the suspended rotor.

2. 2 Force calculation

The reluctance force is derived from the energy stored in the magnetic field. The reluctance force f is obtained from principle of virtual work.

$F=\partial W/\partial S$ ————————-2. 1

Magnetism constant $\mu = \mu r/\mu o$

Where μo= relative permeability depending on the material

W= field energy

∂S= virtual displacement of the hovering body

The force direction is perpendicular to the surface of different material.

The greater the difference in the permeability the greater the force.

For Ferromagnetic materials $\mu r >> 1$, the forces can become very large, thus fulfilling an essential prerequisite for a technical use.

The magnetic resistance of an arrangement is called reluctance. It is inversely proportional to the permeability μr.

Lorentz force F acting on an electric charge Q results from the basic law,

F= Q (E+V*B)

Where E= electric field

V= velocity

B= magnetic flux density

The energy density of feasible electrical fields E in macroscopic technical arrangement is usually a factor of about 100 smaller that the energy density of feasible magnetic fields and the product of charge and velocity (QV) are replaced by current i.

F= i*B

Here the force is orthogonal to the flux lines independent of the air gap and linearly dependent of the current.

2. 3 Design of the hardware components

Active magnetic bearings are created by combining electromagnets, power amplifiers, non contact position sensors and an electric control system.

The control system uses the signals from the position sensors to determine what commands to send to the amplifiers. The amplifiers, in turn, drive the current through the electromagnet coils to produce forces which act on the suspended rotor.

2. 3. 1. Bearing Electromagnets

Magnetic bearings exert forces on the rotor without direct physical contact by using electromagnets. The electromagnets attract the ferromagnetic rotor generating forces. The strength of these forces can then be regulated by controlling the currents in the electromagnet coils.

2. 3. 1. 1. Effect of magnetic field

In a stationary magnetic field the Lorentz force acts perpendicular to the velocity of a charge Q. The magnetic field vector B is perpendicular to the force F and speed V.

F= Q (V*B)

This vector product means that the force is determined only by the component Bw of B which is perpendicular to the velocity.

The unit of Magnetic flux density B is Tesla.

Tesla= N/Am

One Tesla unit may be defined as the flux density of a magnetic field, where a force of 1 N acts on a conductor with a current of 1 A and a length of 1 m.

The total magnetic flux passing through a surface A is the integral of flux density B over the surface.

É¸= ÊƒÊƒA B dA —————— 2. 3

2. 3. 1. 2. A magnetic field generated by an electric current

Magnetic fields can be generated by moving charges (current), alternating electric fields and permanent magnets.

A rotation symmetrical magnetic field is generated around a straight conductor with a constant current i. the magnetic field H is inversely proportional to the distance r from the conductor and its direction is tangential to concentric circles around the conductor.

The magnitude of the magnetic field vector

H= â”, Hâ”,= ————————2. 4

The magnetic field H and the inductance (flux density) B are linked by constitutive law.

B= μo μr H ————————–2. 5

For a vacuum μr= 1

μo= 4*10-7 Vs/A. m

= Magnetic permeability of a vacuum

2. 3. 1. 3. Electromagnetic inductance

Electromagnetic inductance in fact is the inversion of the dynamic effect of magnetic field.

A current is always caused by an electric field. The electric field generating the induction current is produced by a change in the magnetic flux which passes through the surface surrounded by a current. The resulting potential difference is called an induction voltage.

The voltage u induced in a coil with n windings equals the product of the winding number and the derivative of the flux with respect to time t.

U= n ————————————2. 6

2. 3. 1. 4. Flux density assuming constant permeability in the Iron

For calculation of flux density B, the following assumptions are made.

(1) Flux É¸ runs entirely within the magnetic loop with iron cross section, which is assumed to be constant along the entire loop and equal to cross section in the air gap.

(2) The field within the magnetic loop is assumed to be homogeneous both in the iron and in the air gap.

Therefore, we base our calculation on a mean length of the magnetic path and an air gap length 2s.

Magneto motive force ni= $l_{fe}H_{fe}+2sH_a$= Êƒ H ds ——————————–2. 7

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Since according to the flux density B in the iron and in the air gap is identical, field densities H_{fe} and H_a from the above be replaced by

Lfe+2S= ni = NI ————————–2. 8

Solving for B yields,

B= μo ————————————-2. 9

Magnetization of the iron is often neglected. In this case simplification gives,

B= μo ————————————2. 10

2. 3. 1. 5. Inductance L in the circuit

Inductance L is the ration of the so called winding flux generated by one single turn in the coil to the generating current i. For a coil with windings with N turns,

L = ————————- 2. 11

In which total flux generated by the N turns.

From equation above

L= ——————————————-2. 12

The inductance of a bearing magnet is also important to the design of power amplifier. According to the law of inductance, the induced voltage u in a coil with N turns equals

u = N ————————————- 2. 13

2. 4 Magnetic Force

2. 4. 1. Magnetic forces, neglecting the iron

The attracting force of magnets is generated at the boundaries between differing permeability. The calculation of these forces is based on the field energy.

The energy Wa stored in the volume of the air gap, Va= 2sAa. The stored energy Wa is given by,

Wa= BaHaVa= BaHaAa 2s ———————– 2. 14

When the air gap s increases by ds, the volume Va= 2sAa increases, and the energy Wa in the field increases by dWa. This energy has to be provided mechanically. I. e. an attractive force has to be overcome. Thus, force f equals the partial derivative of the field energy Wa with respect to the air gap s.

f = – = BaHaAa = ——————————2. 15

2. 4. 2. Magnetic forces, assuming constant permeability in the iron

To include the effect of iron with a constant, finite permeability, equation 11111 replaces Ba in above equation. The forces resulting in this case,

$F = \mu_o ()^2 A_a \cos \alpha$ ————————— 2. 16

2. 5. Design of Bearing Magnets

2. 5. 1. Load capacity, Magnetic flux

The load capacity of a magnetic bearing is the force obtained with the maximum admissible magneto motive force N Imax.

The achievable magneto motive force Imax, i. e. the product of the maximum current imax and winding number n, depends on the available winding cross section, the mean winding length, and the achievable heat dissipation. The maximum heat dissipation depends on the kind amount of cooling.

2. 5. 2. Admissible Magneto motive Force

The power dissipation of copper Pcu from both axes for the bearing magnet is twice as high, i. e.

$P_{cu} = 2 P_x = 2 R_{cu} i^2_{max}$ ————————————2. 17

The copper resistance Rcu of the winding can be calculated using the wire cross section Ad, the mean length of turns lm, and the specific resistance ρ as follows

$R_{cu} =$ ——————————-2. 18

Considering the bulk factor Kst, the slot cross section An equals the product of wire cross section Ad and the number of turn n:

$A_n K_n = A_d n$ —————————2. 19

If we solve the above equation for wire cross section Ad and insert it into equation 2. 18, we obtain

Pcu = i2max —————————————–2. 20

The admissible maximum magneto motive force

N Imax = n imax

Is now inserted into equation C and solved for N Imax

N Imax = ——————————–2. 21

2. 6 Coil Design

The admissible coil temperature is determined by the choice of the insulation type. The admissible magneto motive force follows from the admissible coil temperature.

The number of turns n is selected in order to achieve the admissible magneto motive force N Imax at a maximum output current imax of the power amplifier. Once n is determined, the wire cross section Ad and subsequently the wire diameter can be calculated using equation B.

The height of the coil head h from the equation below,

H= (d1 + d2) ————————2. 22

N= N Imax / imax —————————-2. 23

This can be used to calculate the admissible power dissipation and as a guide for the space required.

2. 7 Radial bearing

The figure below shows the shows the radial bearing pictorial view. There may be more number of magnets as per the requirement. The sequence of the magnets also changes as per the application. The geometry must be analyzed using any of the analysis method like Finite Element method.

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2. 8 Load capacity

2. 8. 1. Radial Bearings

The specific load capacity can be related to the projection of bearing area db. Assume that the pole shoe width p equals the leg width c. On the bearing diameter d we have one eighth of the circumference per pole at our disposal. Using 50 % of that pole shoe width p, the pole shoe surface is given by

Aa = 0. 50 b ——————— 2. 24

With current Si- alloyed transformer sheets, which are used for bearing magnets, a maximum flux density Bmax of 1. 6 Tesla is recommended. Inserting this value for Ba in equation and considering that the forces of both poles do not act perpendicularly, but at an angle of π/8, we obtain the specific load capacity.

= 0. 50 cos = 0. 50 cos 22. 5 = 0. 37 MPa ———-2. 25

The magnets can be designed for a flux density on the order of 1. 9 Tesla from which a specific load capacity of upto 0. 65 MPa can be produced.

2. 8. 2 Design of Thrust Magnetic Bearings

d bearing diameter

d0 outer diameter

d1 inner winding space diameter

d2 outer winding space diameter

An slot cross section

H pot magnet height

S0 normal air gap

l bearing length

hn slot depth

The pole area for the inner pole

Ap= ——————————–2. 26

Neglecting flux leakage and other non-idealities, the balanced pole area condition is achieved when

= Ap —————————— 2. 27

Further, the radial component of the stator needs to have a minimum area matching that of the pole faces

= Ap ——————————–2. 28

As does the thrust disk

= ——————————————- 2. 29

In any case, the load capacity of the thrust bearing magnet is approximated as

Fmax = ————————————-2. 30

2. 8. 3. Permanent magnet biased magnetic bearings

Bearings which use permanent magnets to generate the bias field and electromagnets to redistribute this field to produce net forces are called permanent magnet biased bearings. The primary advantage of such a scheme is that the electrical power losses associated with generating the bias field are eliminated, so there is less heat to remove from the bearing and it consumes less electrical power.

A common structure for a permanent biased radial AMB magnet set is shown below. This structure has two stator pieces, each with four radial poles in a homopolar arrangement.

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The two stators are separated by an axially polarized ring magnet, which supplies the bias field. Opposing coils are wired in series and also in series with the corresponding coils on the adjacent stator so that only two power amplifiers are needed to control the full set of coils while achieving independent control of the force in the two orthogonal radial directions.

2. 9 Power amplifiers

The power amplifiers convert the control signals to control currents. The power amplifiers contribute most to the losses occurring in a magnetic bearing system. For economical and technical reasons these losses must be kept as low as possible.

2. 10 Sensors

To measure the position of a moving rotor, contact free sensors is used, moreover must be able to measure on a rotating surface. The geometry of the rotor (surface quality) and the homogeneity of the material at the sensor will also influence the measuring results. A bad surface will produce noise disturbances.

3. DESIGN PARAMETERS

3. 1 Losses in the bearing magnets (stator)

3. 1. 1. Copper loss

The copper losses, caused by the control current in the resistance of the coils. The copper losses can be influenced in the design process by balancing the amount of volumes for copper and for iron within the total available volume for the bearing. The copper losses can be reduced by using a larger cross section of the copper wires, obviously leading to more volume for the copper.

3. 1. 2. Iron loss

It is caused by the variations of flux to vary the bearing force and on the other hand variations are caused by the pulse width modulation of the power amplifiers. The variation of the flux density in the bearings is caused by variations of the control current.

3. 2. Losses in the Rotor

3. 2. 1 Aerodynamic loss (wind age loss)

Aerodynamic losses are dominant in high speed applications like compressors where the gas is under high pressure. The air losses are proportional to the cube of circumferential speed.

3. 2. 2 Iron loss (Magnetic Loss)

They are caused by the variation of the magnetic flux density in the iron parts. Changes of flux density induce eddy currents in the iron. These eddy currents generate losses via the electrical resistance.

There are also other losses as per the following (1) Losses in the cables (2) hysteresis loss in the loop.

3. 3. Design criteria

3. 3. 1 Load capacity

The load capacity depends on the arrangement and geometry of the electromagnets, the magnetic properties of the material, of the power electronics, and of the control laws.

3. 3. 2 Speed

The term speed can refer to the rotational speed and the circumferential speed of the rotor in a bearing. The circumferential speed of the rotor is at its largest diameter.

3. 3. 3 Size

There appears to be no upper limit of the bearing size. Problems arising with assembling large bearing leads to special design variations, where the bearing is separated in two halves, or the single magnets are even treated individually.

3. 3. 4 High Temperature

High temperature active magnetic bearings are under development in various places. Operating temperatures of up to 800 ‘ C have been realized.

3. 3. 5 Losses

As there is no contact between rotor and the stator, there is much less losses than the conventional bearings. But the remaining losses have to be taken into account.

3. 3. 6 Precision

The main area of interest in magnetic bearing is how precise it is?

As it leads to specific applications such as lithography, optical scanner, wafer stepper. These machines are key to the semi conductor industry.

4. APPLICATION, ADVANTAGES, LIMITATIONS

4. 1 Practical applications of Active Magnetic Bearing

Magnetic bearing can be used to measure home power consumption in watt hour meter.

Magnetic bearing gives accurate results, so it can be used in high precision instruments.

The main application of the Active magnetic bearing system is to support the equipment in the vacuum. Good example is flywheel energy storage systems. A flywheel in a vacuum has very low wind age losses. Because conventional bearings fail quickly in a vacuum due to poor lubrication.

Active magnetic bearings are used to support maglev trains in order to get low noise and smooth ride by eliminating physical contact surface.

Active magnetic bearing system has very broad application in industrial machines such as compressors, turbines, pumps, motors and generators.

Magnetic bearings are used in semiconductor industries.

Aerospace, ultrahigh speed and molecular scale operations also require the application of Active Magnetic Bearing system.

4. 2. Application of Active Magnetic Bearing System to make Frictionless Compressor

As discussed above the Principle application of the Active Magnetic Bearing System is in rotary machines. Now a day's energy saving in rotary machines is considered of prime importance. To take full advantage of Magnetic Bearing system Frictionless compressor is designed. Frictionless compressor was introduced in 2003. The use of roller bearings and hydrodynamic bearings in Conventional compressors makes the compressor consuming more power. The roller bearings require lubrication.

The use of Magnetic Bearing System in Compressor makes the compressor frictionless. A magnetic bearing system is digitally controlled. The system mainly consists of permanent magnets and electromagnets. The compressor shaft rotates on a levitated magnetic cushion. The use of two radial bearings and one axial bearing which hold the shaft in levitated position.

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The motor and impellers of the compressor are connected to the shaft. When the magnetic bearings are energized, the motor and impellers levitate. Permanent magnetic bearings do the primary work, and electromagnets provide the positioning. Positioning signals are given to the assembly. This will hold the assembly in levitated position. If the assembly goes away from the center point, the signals are changed and the assembly comes to its original position.

The shaft rests on landing bearings. If the magnetic bearings fail, the landing bearings used to prevent a compressor failure. The compressor uses capacitors to smooth ripples in the DC link in the motor drive. The motor becomes a generator instantaneously after a power failure. The capacitors provide enough power to maintain levitation during power failure.

The oil free design of the magnetic bearing system cuts down the maintenance cost by 50 percent. Only a small amount of oil is required to lubricate other components of the system like valves and seals.

4. 3 Comparison of Active Magnetic Bearing System with Conventional Bearing

The reliable operation of the Active Magnetic Bearing system makes it different from the conventional bearings. The reliable operation of the system is just because of no contact between stator and rotor and hence no wears.

When there is overload, the Active Magnetic Bearing system can stop the machine immediately. This adds up one more feature in the active magnetic bearing system.

The long service life of the Active Magnetic Bearing system in some applications such as semiconductor industries, vacuum applications and gas pipeline compressors.

As there is no contact between stator and rotor, there is no possibility of wear. This eliminates the need for lubrication and other system components like pumps, valves etc. There is no particle generation due to wear. So there is no chance of contamination. This keeps the environment very clean.

The rotor and bearing runs at very high speed because of the fact that drag on the rotor is very less as there is no contact. The strength of the rotor material only the limitation against the speed of the rotor and bearing. Not a single bearing can eaual the magnetic bearings for speed.

The speed of the rotor is generally = 4. 5 million DN

Where DN= diameter of the rotor

The use of microprocessor in the system makes system more versatile. The microprocessor runs on advance control algorithms which controls the motion of the shaft. The shaft position depends mainly on the algorithms.

The microprocessor keeps the shaft position within microns and reduces the vibrations.

The vibration in the system is only because of unbalance which is very less. The unbalance is because of high speed machine tool spindles or resonance frequencies.

The Magnetic Bearings can operate through wide temperature range like up to 800 . C at 50000 rpm.

Magnetic bearings can operate in corrosive environments by means of canning both the stator and rotor.

Magnetic Bearings can work under very high pressure. The system can be merged in process fluid under very high pressure.

4. 4 Disadvantages of active magnetic bearing system compared to conventional bearings

Bearing size

Specific load capacity can be defined as maximum load per unit area of application. Magnetic bearings have specific load capacity lower than most conventional bearings. Because of this the bearing size is larger than other conventional bearings.

High complexity

The complexity of the system is because of the fact that use of electronics parts. Also it requires landing bearing. The higher complexity of the magnetic bearings means the early procure price is more than conventional bearings.

Power requirement

Magnetic Bearings consumes power to run the other system components like microprocessor, sensors and electromagnets. Such type of power requirement is not needed for conventional bearings.

Landing bearings

During power failure, the system requires additional landing bearings such that the system keeps running. This is possible by using Landing bearings which are nothing but conventional ball bearings. This is an additional cost in the active magnetic bearing system.

4. 5 Magnet materials

Stator and rotor material

(1) Soft magnetic materials like cobalt based alloys such as

HiperCo 50

HiperCo 50-HS

(2) Iron

(3) Nickel

Electrical components

All electrical components are made of silver wire.

Windings

Windings are of ceramic coated copper with high temperature potting materials.

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