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DESIGN AND TESTING OF AN ACTIVE MAGNETIC BEARING

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ABSTRACT

This paper describes the design and testing of an active magnetic bearing and this works on the principle of electromagnetic suspension which includes an eight pole configuration with four electromagnets which maintains a minimum air gap between stator and rotor. An analysis is carried out that calculates the inductance, flux density and magnetic forces, which in turn balanced to maintain the concentricity of rotor. Validation of theoretical results is planned by designing and experimenting through an AMB test facility.

Keywords:- Active magnetic bearing,8 pole electromagnet.

I. INTRODUCTION

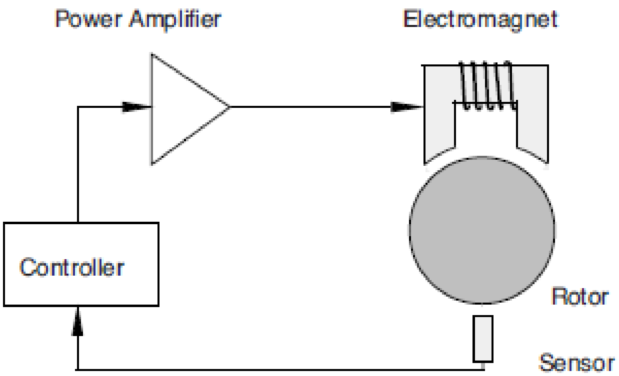

Fig.1.Basic principle of an AMB

An AMB consists of a stator, which contains a pair of electromagnets and the position sensors and the rotor. When the magnetic bearing operating, each pole of the magnetic bearing in the rotor is ideally centred in the corresponding stator magnet so that there is no physical contact between the two and the position sensors detect the local displacement of the shaft.

The AMB use electromagnets to hold the load stable. The AMB is a bearing without physical contact between the rotary and stationary part. In this way the friction and losses of friction can be fully eliminated. Without this physical contact, higher operation speed can be reached and the device requires less maintenance and so the lifetime can be increased too.

II. ELECTROMAGNETIC ANALYSIS

The calculation was done with a maximum of 5 A (DC), and 60 turns on each leg. In these simulations the turns and the current act like constant values, so that they were not changed during the calculations. The main goal was to determine the maximum holding force, i.e. the upper electromagnets in the *y* direction (vertical direction) got 5 A, and in the *x* direction (horizontal direction) the electromagnets on the left and on the right side got 3-3 A. There are three main things on which the holding force greatly depends. The first is the air gap length between the shaft and the legs, the thicker the gap the greater the force. The second is the depth of the apparatus in the *z* direction, twice the depth gets twice force. At last but not least, the thickness of the crowns, the thicker crowns are used, the greater force can be generated [8]. The main problem was to determine the maximum holding force in the *y* direction.

In the radial AMB, two perpendicular radial forces i.e the x axis and y axis force are generated. As already mentioned the four electromagnets are operating in differential mode. With the current in the four electromagnets being regulated independently. For eight pole radial magnetic bearing as shown in fig2.

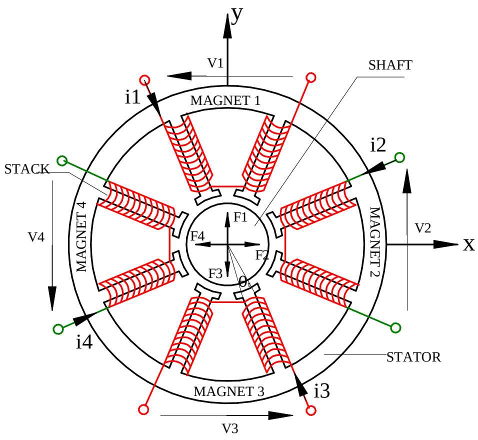

Fig.2. Radial Active magnetic bearing

1.1Electric equivalent circuit

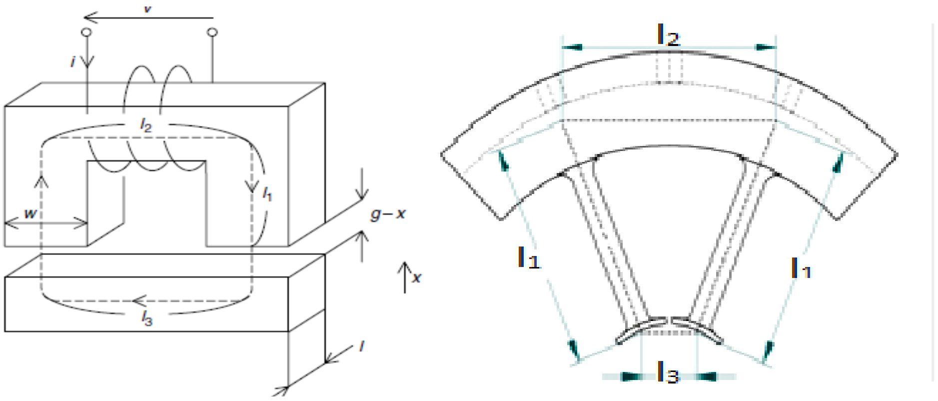

Fig.3. C and I-shaped cores with a winding

Figure 3 shows an electromagnet used to suspend an I-shaped core with a magnetic force. The C-core has a width w with a stack length l. The main flux path is indicated by the dotted line. The lengths of the flux path in the C-core are defined by l_1 and l_2. The flux path length in the I-shaped core is l_3. The winding has N turns. The instantaneous current value is i, so that the MMF is *Ni*. The air gap length is g at the nominal position. A coordinate position x is defined in the I-shaped core position so that the air gap length is (g−x).

The reluctance of the magnetic circuit is defined as

$$R = \frac{l_{fp}}{\mu_{mt} S} \qquad (1)$$

Where,

l_{fp} = flux path length = $l_2+2l_1+l_3$, μ_{mt} = permeability in the material, S = cross-section area of flux path.

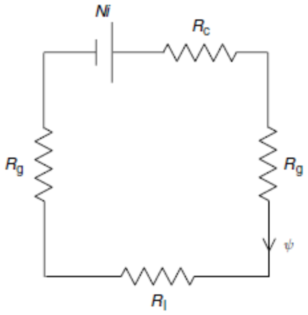

Fig. 4. Equivalent magnetic circuit

Figure 4 shows an "electrical" equivalent circuit for the magnetic circuit of the electromagnet. In terms of MMF (voltage), flux (current) and reluctance (resistance), a constant (dc) magnetic circuit can be treated in the same way as an electric circuit. The main difference is that magnetic reluctance is an energy storage component rather than a loss component. The "dc voltage" source *Ni* represents the MMF generated by the winding current. R_c and R_I are the magnetic reluctances in the C- and I-cores, respectively, and Rg represents the magnetic reluctance at the air gap[1]. These magnetic reluctances are written as

$$R_g = \frac{g-x}{\mu_0 wl} \qquad (2)$$

$$R_c = \frac{2l_1+l_2}{\mu_r \mu_0 wl} \qquad (3)$$

$$R_I = \frac{l_3}{\mu_r \mu_0 wl} \qquad (4)$$

Where μ_0 is the permeability of free space ($\mu_0 = 4\pi\times10^{-7}$ H/m) and μ_r is the relative permeability ($\mu_{mt} = \mu_r\mu_0$). The value of μ_r for iron is typically in the range of 1000–10 000. The relative permeability of air is approximately equal to 1.0. In most cases, the air gap reluctance is significantly larger than the iron reluctance, so that the magnetic reluctance in the iron can be neglected in the following calculation. Therefore the equivalent electrical circuit is simplified.

The flux Ψ is then

$$\Psi = \frac{Ni}{2R_g} = \frac{Ni}{2}\frac{\mu_0 wl}{g-x} \qquad (5)$$

The flux linkage λ_l of the coil is defined as the number of turns N multiplied by the flux passing through the coil,

$$\lambda_1 = \frac{N^2 i}{2}\frac{\mu_0 wl}{g-x} \qquad (6)$$

But inductance is defined as flux linkage divided by the current value ($L=\lambda_l/i$), giving

$$L = \frac{N^2}{2}\frac{\mu_0 wl}{(g-x)} \qquad (7)$$

Nominal inductance L_0 is defined as

$$L_0 = \frac{N^2}{2}\frac{\mu_0 wl}{g} \qquad (8)$$

In addition, the flux density B_0 in the air gap can be derived as

$$B_0 = \frac{\Psi}{wl} = \frac{N\mu_0 i}{2(g-x)} \qquad (9)$$

Electromagnetic force from the flux density in the air gap is given by,

Let us define the air gap area S as 2wl so that the magnetic force is expressed as in the well-known Maxwell stress equation where,

$$F = \frac{B_0^2}{2\mu_0}S \qquad (10)$$

This equation gives a straight forward insight into magnetic force generation. It can be said that the magnetic force is proportional to the square of flux density in the air gap. The force is also proportional to the air gap area.

2.2 Details of studied structure

The different parameters are used for AMB are as follows

Table.1. Different parameters used

Parameter	Value
Inner diameter of the AMB	31mm
Outer diameter of the AMB	100mm
Height of the stack	25mm
Operating air gap	1mm(Radial)
Shaft diameter	29mm

III. MODELLING

Modelling of Active magnetic bearing by CAD software, Solid edge ST5. The layout of the AMB under design can be seen in Figure 5. In the centre the shaft can be seen surrounding it by the four electromagnets. The shape of the legs is rounded internal (crown style legs) pole to gain greater holding force. The 2D and 3D model of Active magnetic bearing are as follows with crown style legs in the pole.

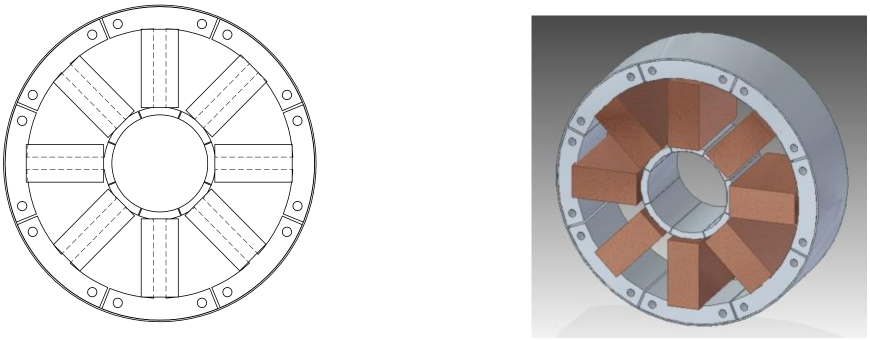

Fig 5. 2D and 3D model of Active magnetic bearing

IV. FABRICATION OF AN ACTIVE MAGNETIC BEARING

4.1 Stator: Stator of an active magnetic bearing is a magnetic circuit which acts as a path for magnetic fields produced in it. Hence more care must be taken while selecting an appropriate material for stator. Selecting an appropriate material for stator requires knowledge about ferromagnetic materials and its properties. Saturation and permeability based on that choose a ferromagnetic material (silicon steel) that could have high permeability and saturation level.

According to our needs sheet steel will be the best choice to be a stator material as it has better permeability and saturation levels. Sheet steel laminations are 0.5mm thick; the laminations of completely laminated poles have rivet holes for the assembly of poles. The laminations are assembled on steel rods and the whole is then pressed between thick steel end plates.

4.2 Windings: The actuator coils of active magnetic bearing are wound with round copper wire. These coils are insulated with enamelled copper are used.

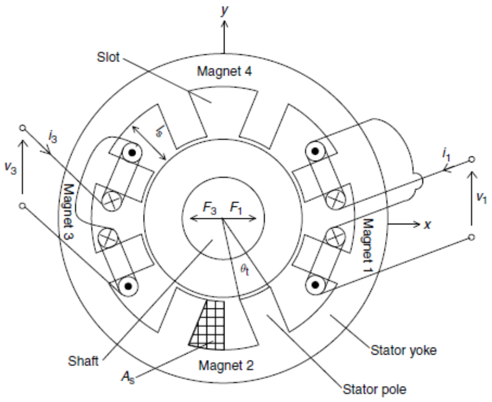

Fig.6. Winding scheme

Figure 6 shows the cross section of a typical radial active magnetic bearing. The rotor is cylindrical in shape with a centre shaft surrounded by ferromagnetic material such as laminated silicon steel. The stator surrounds the rotor and has eight poles. The areas between the stator poles are the slots and contain the windings. The stator yoke completes the magnetic paths of the eight stator poles shown in the example. Width of the stator yoke is designed to be wide enough to avoid magnetic saturation and produce high mechanical stiffness in order to avoid vibration caused by radial magnetic forces.

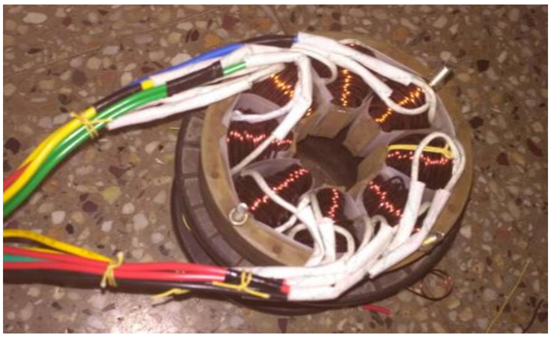

Fig.7.Pictorial view of Active magnetic bearing

V. EXPERIMENTAL SETUP

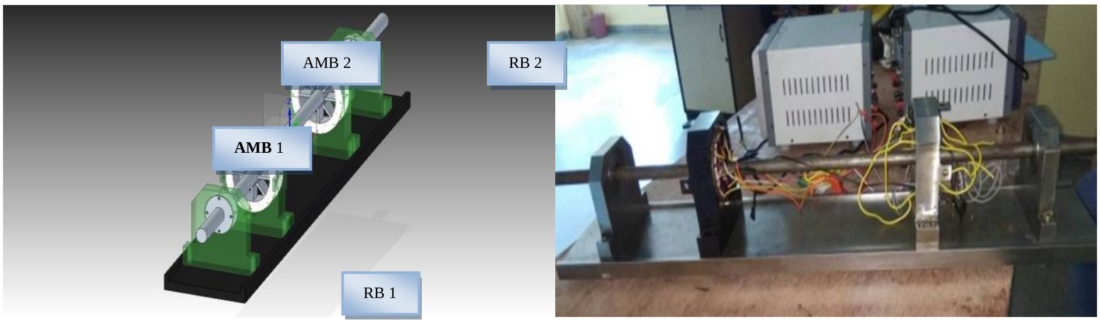

Fig .8. Experimental setup

A typical Active magnetic bearing system contains two Radial active magnetic bearing and two retainer bearing this arrangement is as shown in fig 8.A rotor supported on AMB's will also have retainer bearings to support the rotor when AMB system is not supporting and also in the event of an overload or failure condition of the magnetic bearings. These are usually located adjacent to the radial magnetic bearing.

VI. RESULTS AND DISCUSSION

Figure 9 shows the plot between current through the coil and the pulling force of the fabricated actuator.

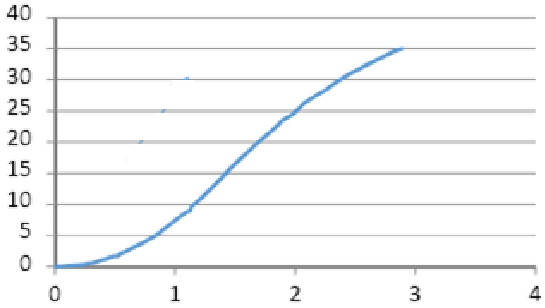

Fig .9. Plot of pulling force of the magnetic coil in kgf versus the coli current in amperes

To characterized the designed electromagnetic actuator, the current in the magnetic coil is gradually increased from minimum value of zero to a maximum value of 3.5A and the corresponding values of pulling force is noted down.

VIII. CONCLUSION

Basic structure, analysis and mathematical model with fabrication of an Active magnetic bearing are done. The designed Active magnetic bearing system is tested to be capable of supporting load up to 10kgf with an air gap of 1mm and when operating within its linear region.

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