International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-2, December 2019

Force Analysis of Single Axis Actuator Used in Active Magnetic Bearing (AMB)

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Abstract*: This paper presented the force analysis of single coil actuator for Active Magnetic Bearing (AMB) system. Actuator is the most important segment of AMB system. In the bearing system rotor should be levitate before rotation. For the levitation required force is generated by actuator. For the specific structure attractive force is different. These force analysis is done in this manuscript. Depending upon the force appropriate structure can be used for design a perfect AMB system. Here force analysis is performed in ANSYS Maxwell software and characteristics graphs are presented in 2D and three dimensional plots are constructed using MATLAB for the better observation.

Keywords: Force analysis, ANSYS Maxwell, MATLAB.

I. INTRODUCTION

This manuscript demonstrates the force profile for different structure of actuators used is AMB design. The active magnetic bearing can support a rotor shaft which has no contact with the stator, it is done by magnetic forces produced by a control electromagnet, and it is called active magnetic bearing. Electromagnetic force depends on different factors like actuator type, core size, and number of turns. In this paper to check the behavior of actuator force profile similar size of core and same number of turns are used in the winding. Here three different type of actuator is used. Different types of structures for active magnetic bearing is shown in figure-1[1][2][3][4].

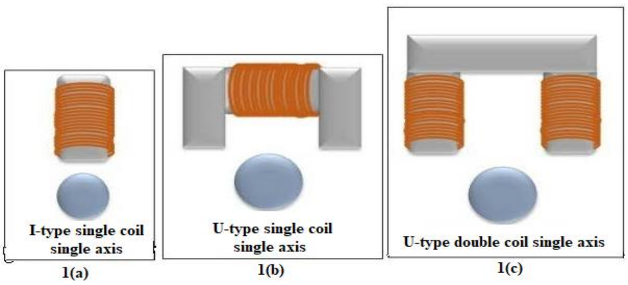

Fig. 1. **Schematic diagram of (a) single coil single axis I-type actuator (b) U-type single coil single axis actuator (c) U-type double coil single axis actuator**

Revised Manuscript Received on December 30, 2019.
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Here force analysis is done for 10 different air gaps between actuator and rotor for all the strictures starting from 2mm to 20mm.

II. FORCE ANALYSIS OF ACTUATORS

The stator part of an AMB is an electromagnet which acts as an actuator, and this actuator produced a suspension force. Magnetic flux is produced when a current is passing through the coil mounting around a ferromagnetic material which attracts nearby another ferromagnetic material. The instantaneous voltage equation across the magnetic coil is given in equation 1 and the magnetic force produced is shown in figure-2.

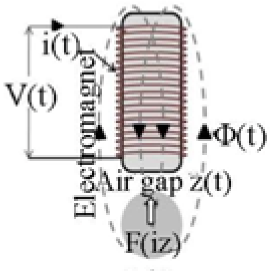

Fig. 2. **Simplied levitation system**

The AMB system is a strongly non-linear system. So, the linearization of a system is necessary.

$$v(t) = Ri(t) + \frac{d}{dt}\left[L(x)i(t)\right] \quad (1)$$

Here, 'R' is the resistance of the coil, 'i(t)' is the current flowing through the winding and 'V(t)' is the voltage applied to the AMB system [5][6][7]. The force of attraction between the actuator and rotor is non-linear. The force expression is given by

$$F(i,x) = \frac{d}{dx}\left[\frac{1}{2}L(x)i(t)\right]^2$$
$$F(i,x) = \frac{\mu_0 N^2 A}{4}\left[\frac{i(t)}{x(t)}\right]^2 \quad (2)$$

Where, 'N' is the number of coil turns, 'A' is the magnetic pole face area, 'i(t)' is the instantaneous current and x(t) is the distance between pole face of the electromagnet and the rotor. When the force produced by the electromagnet is equal with the gravitational force, then the rotor is levitated in the air without any physical support.

In this way, the rotor will levitate and can be rotated in the air freely without any physical contact with the actuator as a result of less noise, finite speed, long life and heat less of a system [8] [9] [10].

Using Newton 2nd law of motion, the mechanical equation of AMB system can be written as

$$F = m.g - C\left(\frac{i}{x}\right)^2 \quad (3)$$

Where m is the mass of the rotor, ‘g’ is the gravitational constant, ‘i’ is the current through the coil and ‘x’ is the ball position.

The critical part of the AMB system is its actuator. Amplifier and actuator together convert the electrical signal receives from the controller into a force applied to rotor shown in figure-3. In general, the combination of a random array of amplifiers and electromagnets construct the actuator for an AMB system [11] [12] [13] [14].

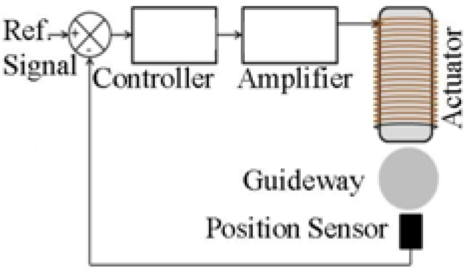

Fig. 3. Close loop model of AMB system

III. DESIGN AND SIMULATION

Electromagnetic structures for the active magnetic bearing is designed and simulated in ANSYS Maxwell software. Properties of material used in design are shown in table-1. Material used for actuator and rotor is iron and winding is done using core wire. Designed actuator for three different structures is shown in figure-4. Force analysis is performed for 10 different air gaps for all the structures and also inductance is measured using ANSYS. Figure-5 shows the force analysis for I-type single coil single axis actuator and the force is showing in the figure for 10mm air gap. Figure-6 and figure-7 shows the force analysis for U-type single coil single axis actuator and double coil single axis actuator respectively.

Table 1 Properties of materials used in ANSYS Maxwell 2D

Sl. No	Particulars	Rotor (Iron)	Actuator (Iron)	Coil (Copper)	Units
1	Relative permeability	4000	10000	0.99	
2	Bulk Conductivity	1030 0 000	10300 000	58000 000	S/m
3	Thermal conductivity	89	89	400	W/mC
4	Mass Density	7880	7880	89353	Kg/m^3
5	Poisson's Ratio	0.38	0.38	0.48	

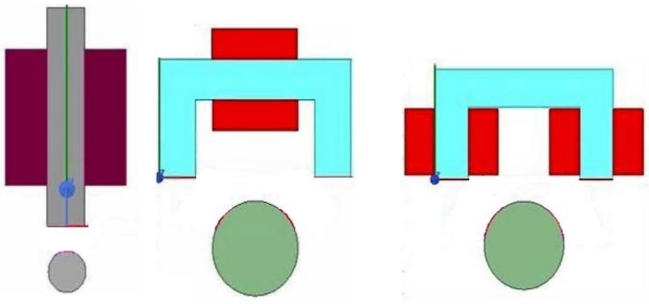

Fig. 4. Three different actuator structure designed in ANSYS Maxwell

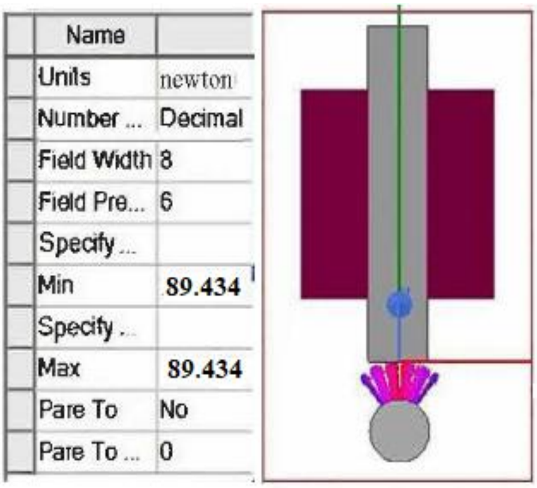

Fig. 5. Force analysis for I-type single coil single axis actuator

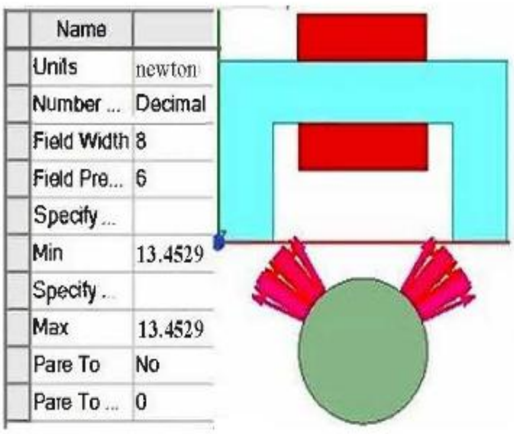

Fig. 6. Force analysis for U-type single coil single axis actuator

From the figure-5, figure-6 and figure-7 it is observed that I-type actuator force is more than other two structures. The force and inductance values are find out for 10 air gaps starting from 2mm to 20mm with an air gap 2mm.

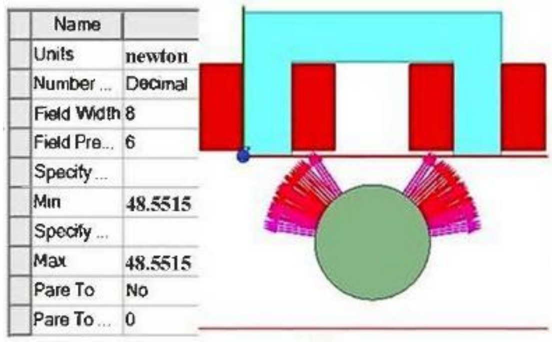

Fig. 7. **Force analysis for U-type double coil single axis actuator**

IV. RESULT AND DISCUSSION

Force analysis and inductance find out for ten air gaps for I-type actuator and tabulated in table-2. Characteristics graph is plotted using this data and shown in figure-8. It si observed that force profile is decreasing with the increasing in air gap. For the observation how inductance and force are changing with the increasing in air gap a three dimensional plot is construct using MATLAB and shown in figure-9.

Table-2 Force and inductance for 10 air gaps of I-type actuator

Sl. No.	Air Gap (mm)	Force (Newton)	Inductance (mH)
1	2	159.54	42.291
2	4	145.65	41.056
3	6	131.86	40.356
4	8	112.64	39.786
5	10	89.343	39.023
6	12	71.985	38.563
7	14	55.684	37.123
8	16	37.454	36.256
9	18	20.654	35.986
10	20	12.258	35.065

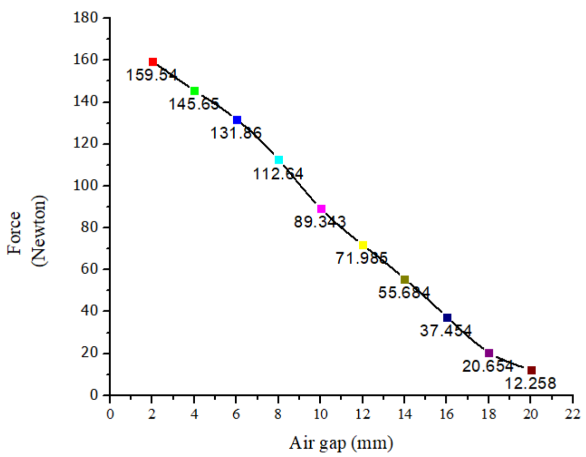

Fig. 8. **Charecteristics graph between force and airgap for I-type actuator**

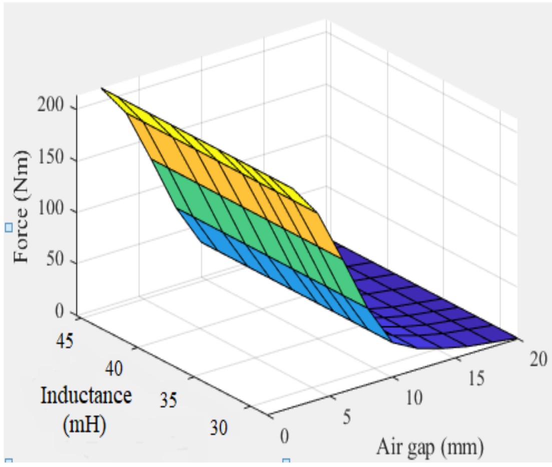

Fig. 9. **Three dimentional plot between force, inductance and airgap for I-type actuator**

Force and inductance values for U-type single coil single axis actuator is tabulated in table-3. Characteristics graph is plotted using this data and shown in figure-10. It si observed that here also force profile is decreasing with the increasing in air gap. For the observation how inductance and force are changing with the increasing in air gap a three dimensional plot is construct using MATLAB and shown in figure-11.

Table-3 Force and inductance for 10 air gaps of U-type single coil single axis actuator

Sl. No.	Air Gap (mm)	Force (Newton)	Inductance (mH)
1	2	51.865	37.891
2	4	43.656	36.556
3	6	34.956	36.256
4	8	18.698	35.686
5	10	13.453	35.123
6	12	8.2651	34.863
7	14	3.2564	34.223
8	16	1.2556	33.656
9	18	0.2365	32.086
10	20	0.0365	31.565

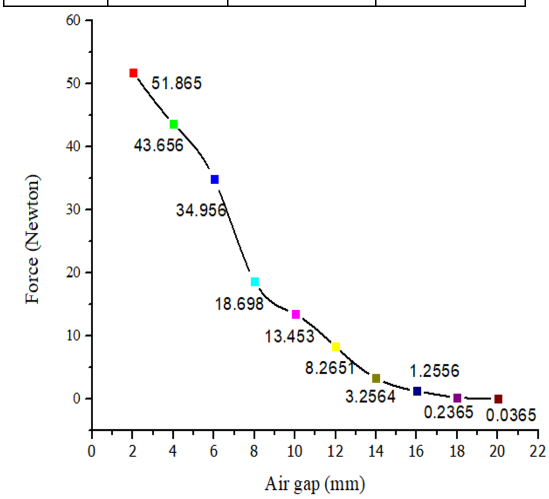

Fig. 10. **Charecteristics graph between force and airgap for U-type single coil single axis actuator**

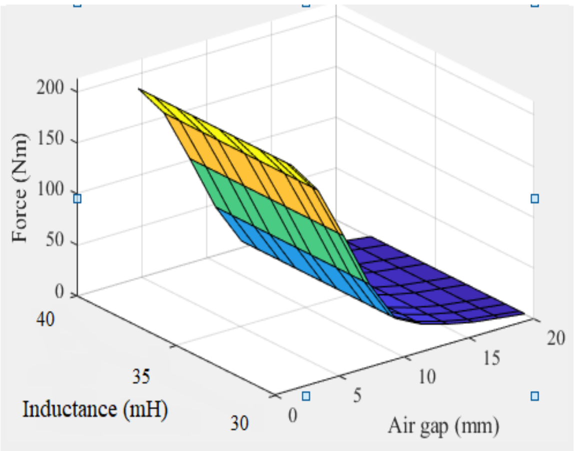

Fig. 11. **Three dimentional plot between force, inductance and airgap for U-type single coil single axis actuator**

For the U-type double coil single axis actuator ANSYS data are tabulated in table-4. Using these data 2D and 3D graph is plotted and shown in figure-12 and figure-13. Here also force is decreasing with the increase in air gap.

Table-4 Force and inductance for 10 air gaps of U-type double coil single axis actuator

Sl. No.	Air Gap (mm)	Force (Newton)	Inductance (mH)
1	2	106.45	39.365
2	4	95.684	38.456
3	6	81.365	38.054
4	8	68.659	37.689
5	10	48.552	36.156
6	12	42.562	35.789
7	14	28.659	34.659
8	16	21.326	34.056
9	18	9.1254	33.865
10	20	1.5684	33.365

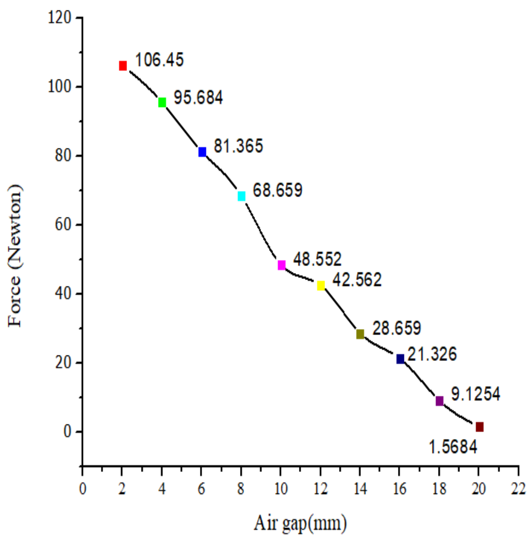

Fig. 12. **Charecteristics graph between force and airgap for U-type double coil single axis actuator**

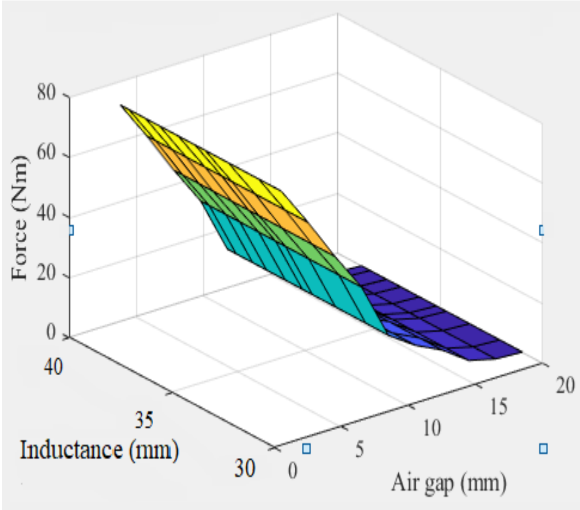

Fig. 13. **Three dimentional plot between force, inductance and airgap for U-type double coil single axis actuator**

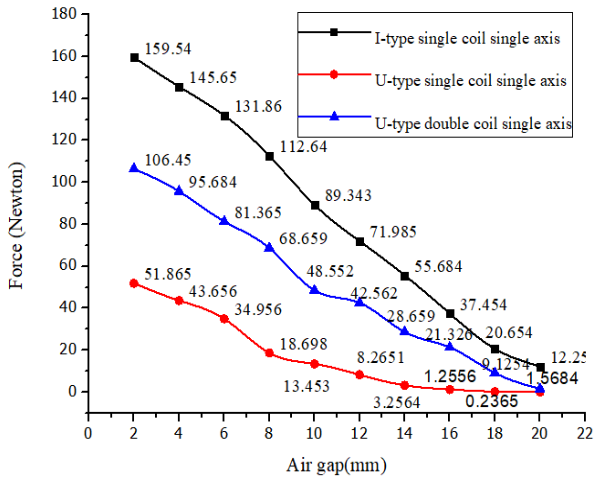

Fig. 14. **Force profile for I-type single coil single axis, U-type single coil single axis and U-type double coil single axis actuator**

To know the force comparison between actuators force data are compared and result is shown in figure-14. Here I-type single coil single axis actuator force is more in all the air gaps than U-type single coil and double coil single axis actuators.

V. CONCLUSION

In this manuscript force analysis is performed for three different electromagnetic actuators. Here it is observed that force profile of particular actuator is decreasing with the increasing is air gap. Comparison is done between actuators, where I-type single coil single axis actuator force is more than others. From this analysis it is found that designing a better active magnetic bearing system I-type actuator can be a good choice, because for the same design and material I-type actuator performance is better.

ACKNOWLEDGMENT

The authors of this paper wish to thank Science and Engineering Research Board (SERB), Department of Science and Technology, Govt. of India for sponsoring the project.

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