System Identification of the Axial Active Magnetic Bearings with Solid Core

Yasuhiro.Yukitake , Hirochika.Ueyama

R&D Center, Koyo Seiko Co., Ltd.
24-1 Kokubuhiganjyo, Kashiwara, Osaka 582, JAPAN
tel:+81-729-78-5018;fax:+81-729-77-7675

Abstract : Recently, the Active Magnetic Bearing came to be widely used for several applications, because of its unique advantages such as Lubrication - Free, Less - Vibrations, Maintenance - Free and so on.

Furthermore,thanks to the current advanced controller design tool, for example Matlab, MatrixX, etc.. it became more freely to use this A.M.B.technology for industrial application.

Nowadays, by means of these computer aided design tool, the controller for A.M.B plant including essentially unstable position stiffness Ks are easily designed using many kind of modern control theory for example, LQE, LQR, H infinity, mu synthesis, LMI, QFT, etc.

But, even if in the case of using these theory, to know the plant for which we want to control is the most interesting and important issue.

In another word, less knowledge for the plant characteristics leads to rather poor performance controller design result, in general.

Therefore, in this paper, the authors focusing into the identification of the Axial Magnetic Bearing System having solid core which seems to have the most uncertainty, compared to Radial Magnetic Bearing having laminated construction, due to the Eddy Current Effect.

The Eddy Current Effect in the Axial Magnetic Bearings is rather large because of its non-laminated construction which bring large degree of phase lag and roll off in the transfer function between the magnetizing current to attractive force generated in the air gap of electromagnet in the frequency domain.

The final goal of this projects is

1)Building up the automatic identification tools for this purpose.

2)Evolution for the contribution of material specific resistance to this phase lag and roll off.

3)Finding out the optimal ferromagnetic material for this kind of actuator.

and

4)Finding the equivalent circuit which can describe the electromagnet actuator which having the afore mentioned eddy current effect and phase lag.

1 INTRODUCTION

Axial Active Magnetic Bearing particularly is generating higher eddy current than Radial Active Magnetic Bearing by reason of it is constructed by solid core. Therefore, The dynamic characteristics of Axial Active Magnetic Bearing System is strongly affected by eddy current effect in the electromagnet.

But Axial Active Magnetic Bearings, one degree of freedom system, is simple to be modeled and is more convenient to be identified than Radial Active Magnetic Bearing System which having multiple input multiple output system such as 2input-2output system.

In previous paper, we can find in the literature, with regard to eddy current effect, roughly the papers are classified two categories.

1) Active Magnetic Bearing System was affected by eddy current[1, 2]

2) Method of system identification with eddy current [2, 3, 4]

With regard to second category of 2) did not show a concrete value for eddy current effect.

In this paper,as the first step of this projects, we have been focusing at the Axial Active Magnetic Bearing System and we assume one of the equivalent circuit and corresponding transfer function to describe eddy current effects. We estimate the value of parameter regarding to eddy current effect from curve fit of transfer function between measured one and simulated one with the theoretical model.

2 ACTIVE MAGNETIC BEARING AND PARAMETER K

Fig1 shows a simple Active Magnetic Bearing System. The force F provided by two opposite electromagnets is

$$F = K\left(\frac{I_0 + I_c}{X_0 + X}\right)^2 - K\left(\frac{I_0 - I_c}{X_0 - X}\right)^2 \qquad (1)$$

Here, I_0 ; nominal current, I_c ; control current, X_0 ; nominal air gap, X ; the deviation from the nominal position, and K is

$$K = \frac{N^2 A \mu_0}{2X_0} \qquad (2)$$

Which is electromagnets characteristics parameter that consisting of μ_0 ; permeability, N ; number of coil turn and A ; attractive area of core.

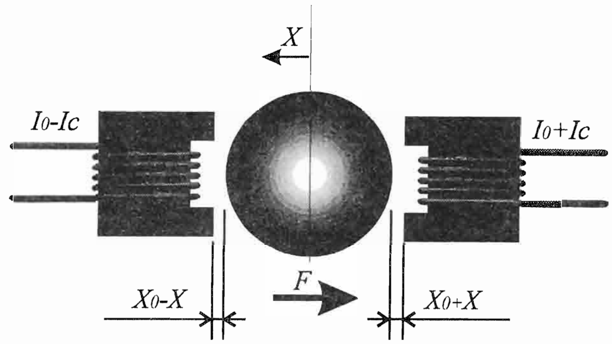

Figure 1: Reduced system

3 EQUIVALENT CIRCUIT

Fig 2 shows a equivalent circuit of electromagnets considering eddy current effect. *Re* and *Le* were introduced parameter as the expression of impedance concerned with eddy current.

The effective current (I_E) which contribute to actual attractive force, and I_e is current of no effect on attractive force.

The basic idea of this equivalent circuit is

a) For the DC current,circuit resistance is R. Eddy current Ie is not generated when total current I_T is DC, and I_T flow only in L. It must be not flow to Le and Re from node A.

b) When I_T have frequency component such as control signal, current T_e will flow to R_e and L_e, the magnitude of I_e depend upon the ratio between impedance of L_e and impedance of series circuit of R_e and L_e.

For that purpose Re and Le connect in series, and moreover node A is arranged between R and L.When I_T have high frequency component, impedance of Le are affected by frequency of I_c,and also L. Therefore,unless L, L_e, and R_e are specific value, the ratio of I_E to I_e is varied by frequency of AC component I_c too.

In the next section we well introduce the transfer function of Ge which describe the dynamics from total current I_T to effective current I_E.

4 MODELING OF ACTIVE MAGNETIC BEARING SYSTEM

Fig3 shows a block diagram of Axial Active Magnetic Bearings System. Ga is transfer function of power amp. Ge is also eddy current which based on afremntioned equivalent circuit. Gm is force/current factor. Gx is position stiffness. Gs is transfer function of displacement sensor. Gc is transfer function of controller. The input port of disturbance signal and output of displacement signal are placed power amp and sensor, respectively. Every component and transfer function except for Ge is already known,therefore we can estimate the parameter of Ge from measured closed loop transfer function of the system.

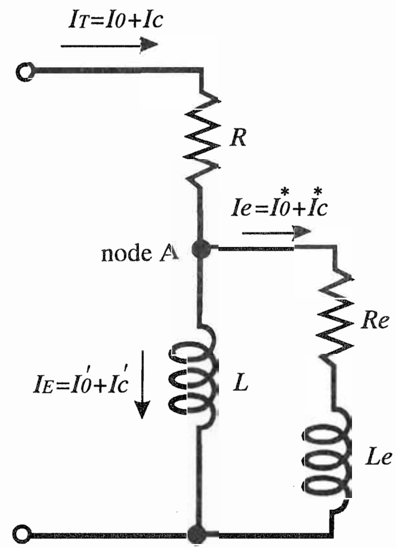

Figure 2: Equivalent Circuit of Electromagnet

5 AXIAL MAGNETIC BEARING SYSTEM CONFIGURATION

Fig4 shows Axial Active Magnetic Bearing used in our test rig for getting measured data. Table 1 shows specific data of electromagnet .

Table 1 : Specific data of Axial Magnetic Bearing

Parameter	Value
Outer diameter of disk	75mm
Outer diameter of core	120mm
Inner diameter of core	40mm
Nominal air gap	0.3mm
Nominal current	0.2A
Number of coil turns	405turns
K of material A	$62.5Nmm^2/A^2$
K of material B	$63.2Nmm^2/A^2$

The two opposed electromagnets have the same dimensions and number of coil turns. Core materials are employed low carbon steel(material A) and soft magnetic stainless steel(material B). Material B has about six times higher electric resistance of material A, and is expected to generate less eddy current than material A. Nominal gap is 0.3mm, nominal current is 0.2A. K is represented by equation (2).

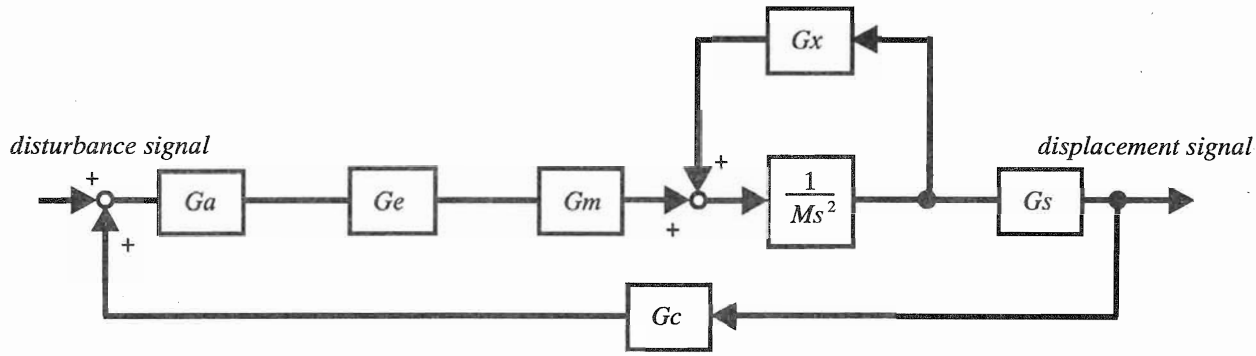

Figure 3: Block Diagram of Axial Active Magnetic Bearings System

Test rig is 5-axis controlled magnetic bearing spindle which was developed for turbo molecular vacuum pump. Above-mentioned Axial Active Magnetic Bearing can levitate the spindle weighting 10.4 Kg. When measurement of the closed loop transfer function (C.L.T.F) was carried out, the spindle was set horizontally.

C.L.T.F can be measured for the excited state of closed feedback loop system. Disturbance force can be generated by practice electromagnet with swept sin signal injection ranging from 5 to 1000Hz to the power amp. Displacement measurement of the shaft is available from sensor signal.

Controller was conventional analog PID type. In this test, we selected two different type of PID parameter respectively.

Type A

$$Gc = \frac{1.24s^3 + 1.90 \cdot 10^5 s^2 + 2.63 \cdot 10^7 s + 3.79 \cdot 10^7}{s^3 + 1.21 \cdot 10^4 s^2 + 2.13 \cdot 10^7 s + 4.53 \cdot 10^5} \tag{3}$$

Type B

$$Gc = \frac{1.03s^3 + 2.32 \cdot 10^5 s^2 + 2.19 \cdot 10^7 s + 3.77 \cdot 10^7}{s^3 + 1.21 \cdot 10^4 s^2 + 2.13 \cdot 10^7 s + 4.53 \cdot 10^5} \tag{4}$$

6 THE RESULT OF MEASURED CLOSED LOOP TRANSFER FUNCTION

Fig5 and Fig6 show the result of measured C.L.T.F. The resonance point of material B move to high frequency by contrast with material A. Moreover,for both material, C.L.T.F are almost the same in very low frequency. It is evident that material B generate higher attractive forces than material A in high frequency region.

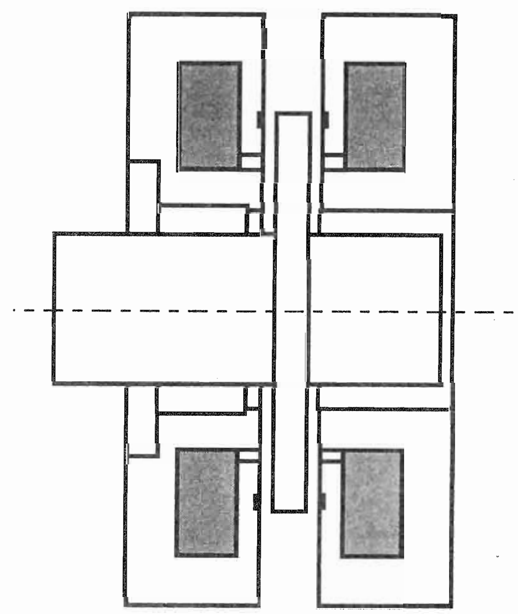

Figure 4: Construction of Axial Magnetic Bearing

7 RESULT OF CURVE FIT

Fig7 to Fig10 are result of curve fitting data by changing R_e and L_e to fit the measured data of C.L.T.F. Table 2 shows value of fitted result for Re and Le. Material B's value of Re and Le are larger than material A's. It is natural result,judging from considered equivalent circuit and electric resistance of both material.

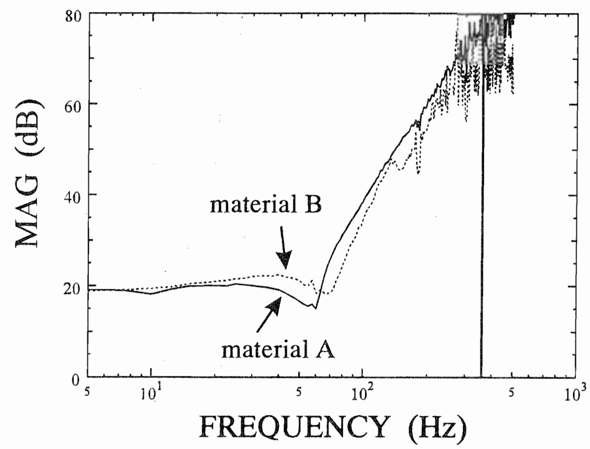

Figure 5: Result Gc type A

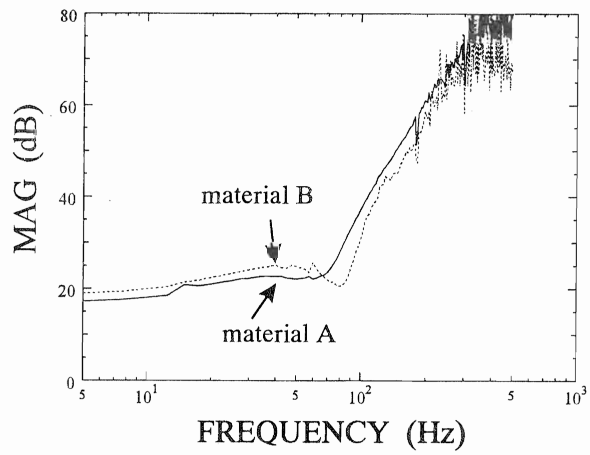

Figure 6: Result Gc type B

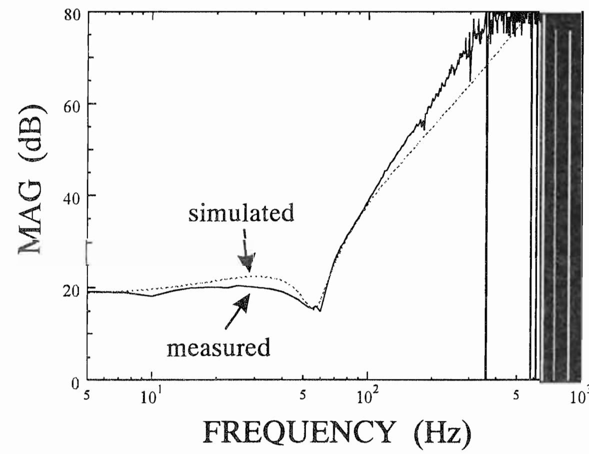

Figure 7: Fitting of material A Gc Type A

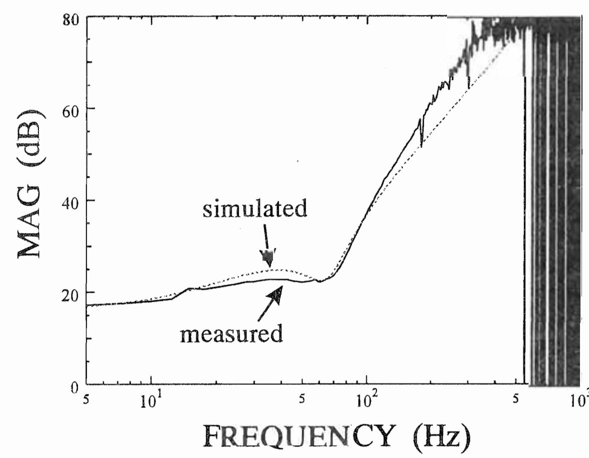

Figure 8: Fitting of material A Gc Type B

table 2 : Identified value of *Re* and *Le*

Material	Gc	Value of *Re*	Value of *Le*
material A	A	70	120
material B	A	110	170
material A	B	70	120
material B	B	110	130

8 CONCLUSIONS

There was almost no difference in the electromagnet constant K (for DC component) for both material A and B used for Axial Magnetic Bearings stator.

But, it is obvious that they have their own frequency dependent characteristics, because of their difference in their measured closed loop transfer function.

The curve fitting result for both material and for two different PID controller show quite nice coincidence with the simulated results based on the introduced equivalent circuit in the region under 200Hz, but on the other hand , in the more higher frequency region, the degree of the error will tend to increase.

Therefore, the introduced equivalent circuit is only valid in the lower frequency region, and it is clear that they still have unknown dynamics or another frequency dependent component in this system.

References

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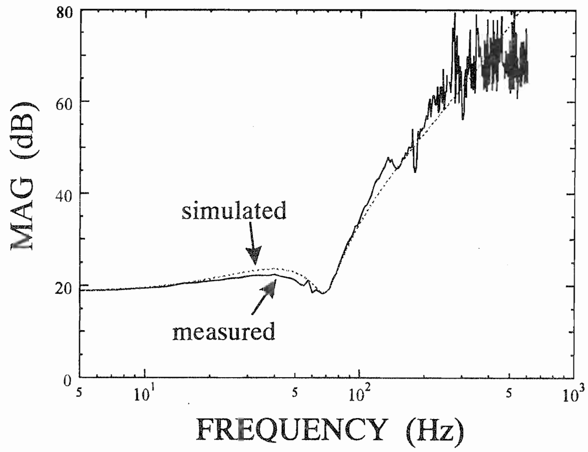

Figure 9: Fitting of material B Gc Type A

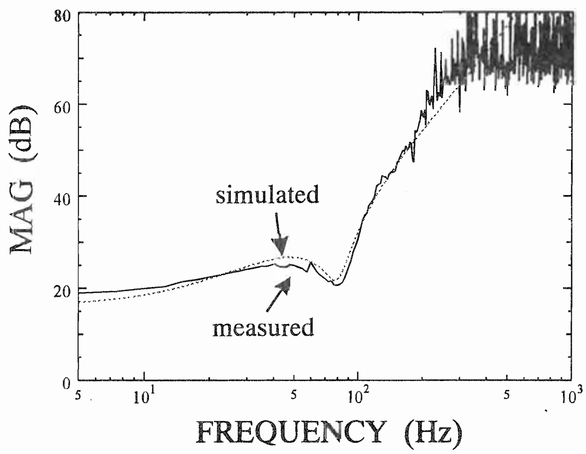

Figure 10: Fitting of material B Gc Type B

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