Dynamic Simulation of Zero Power Control with Load Observer in Controlled-PM Levitation by Finite Element Method

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Abstract—This paper deals with the scheme that it improved performance of magnetic levitation is used widely, but it is complicated and difficult to control due to having nonlinearity of gap and current. So, the dynamic simulation of zero power control with load Luenberger observer by finite element method for considering nonlinearities is adopted. To verify the feasibility of zero power control scheme, experimentation and simulation are carried out. The TI DSP TMS320C240F is used for experiment and time stepped finite element method is used for simulation.

I. Introduction

A magnetic levitation system without current collector requires a minimum driving power consumption, because it has battery for supplying driving electric power by itself. But in the conventional electro magnetic suspension, it is necessary to excite electromagnet to maintain balanced levitation gap, since it consumes large electric power. For that reason, the magnetic levitation system using hybrid permanent magnet called CPM (Controlled Permanent Magnet) has become a proven method in decades as an energy saving MAGLEV system and DC power loss of the CPM electromagnet under load variation can be significantly reduced by using the zero-power-control method proposed by Morishita, etc, because CPM uses the electric power only in the transient condition [1,2].

An analytical method, which is utilized widely in the comercial simulation softwares, is inaccurate to model levitation system that has nonlinearity. Therefore, we should use dynamic FEM analysis that can consider its nonlinerarity.

In this paper, a luenberger observer is adopted to estimate variable . To verify the feasibility of control scheme, variable load experimentation and simulation are carried out. The control scheme is implemented using TI DSP TMS320F240-based hardware, and the time stepped finite element method is used for the simulation [3].

II. System Modeling and Control Tehorem

A. System modeling

Fig. 1 shows magnetic levitation model being consisted stator and CPM.

(1), (2), (3) show the linearized equations of CPM having nonlinear characteristics. In these equations, z_0, i_0 are equilibrant gap, current. Δz, Δi and ΔE expresses the deviation from each stable equilibrant point. B_r is residual magnetic flux density and N is coil turns. We can reasonably assume that (4) is zero because of the relatively long time constant of the load.

$$m\frac{d(\Delta v)}{dt}=\frac{S}{\mu_0}\left(b\frac{(B_r-bi)}{(1+az_0)^2}\Delta i+a\frac{(B_r-bi_0)^2}{(1+az_0)^3}\Delta z\right) \quad (1)$$

where, $a=\frac{\mu_m}{\mu_0}\frac{2z}{l_p}$, $b=\frac{\mu_m}{l_p}N$

$$\frac{d(\Delta i)}{dt}=\frac{1}{L_0}\left(-R\Delta i+\Delta E\right) \quad (2)$$

$$\frac{d(\Delta z)}{dt}=\Delta v \quad (3), \qquad \frac{d(\Delta F_L)}{dt}=0 \quad (4)$$

B. Control Theorem

Zero power control can be only used when we know balanced gaps with variable load. So, if we cannot sense the balanced gap, it is difficult to control the levitation system.

Accordingly, a new method considering variable load should be used, such as a gap compensator using observer. Assume observed state $\hat{x}(t)$, actual state $x(t)$, observed output $\hat{y}(t)$, actual output $y(t)$, the state observer is made in (6). At this time, the state observer uses Full Order Luenberger Observer (FOLO).

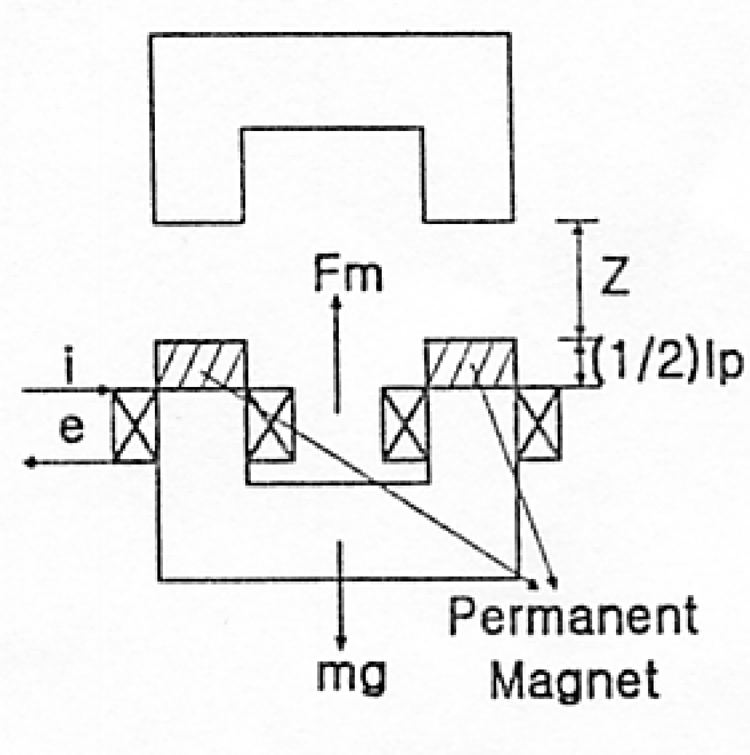

Fig. 1. Magnetic levitation model

L matrix compensates state observation error $x(t)-\hat{x}(t)$. From the result of observability and controllability of system, we can make gap compensator using full order load observer considered variable load. To improve system stability, the state feedback is added to the system. Fig. 2 shows the block diagram of the zero power control with gap compensator.

$$\frac{d}{dt}\hat{X} = A\hat{X} + Bu - L\{X - \hat{X}\}$$
$$X = (\Delta z, \Delta v, \Delta i, \Delta F_L)^T, B = (0,0,b_3,0)^T, u = E \quad (6)$$

III. Analysis of Simulation and Experiment

Fig. 3 shows flow chart of the analysis. In the motion analysis, the speed and acceleration value can be obtained by using the attraction force calculated by Maxwell stress tensor. TI DSP TMS320F240 is used to accomplish Luenberger load observer and zero power control. Fig. 4 shows simulation and experiment results. In Fig. 4 (a) and (b), the variable load [1kg] is loaded for 2.0[sec]. The upper is gap output wave and the lower is current output wave. When loaded, the balanced gap is diminished from the no load state because the balanced gap must be moved to the point that the force of gravity is equal to the electromagnetic force for zero power control. The transient time of experimental results are longer than simulation ones because the mover is restricted instantaneously when the load is applied by hand.

IV. Conclusion

This paper describes the finite element analysis of the zero power controlled magnetic levitation system with observing load variation. To accomplish zero power control, Luenberger load observer is adopted. Simulation is carried out by time-stepped finite element method and moving mesh technique and DSP is used for experiment. The simulation results are matched with the experiment results.

Acknowledgment

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References

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[2] M. Morishita et al., "A new Maglev system for magnetically levitated carrier system," *IEEE Trans. On Vehicular Tech*, vol. 38. no 4, pp. 230-236, 1989.

[3] TMS320F240x DSP Controller Reference set and Reference guide, *Texas Instrument*. 1998.

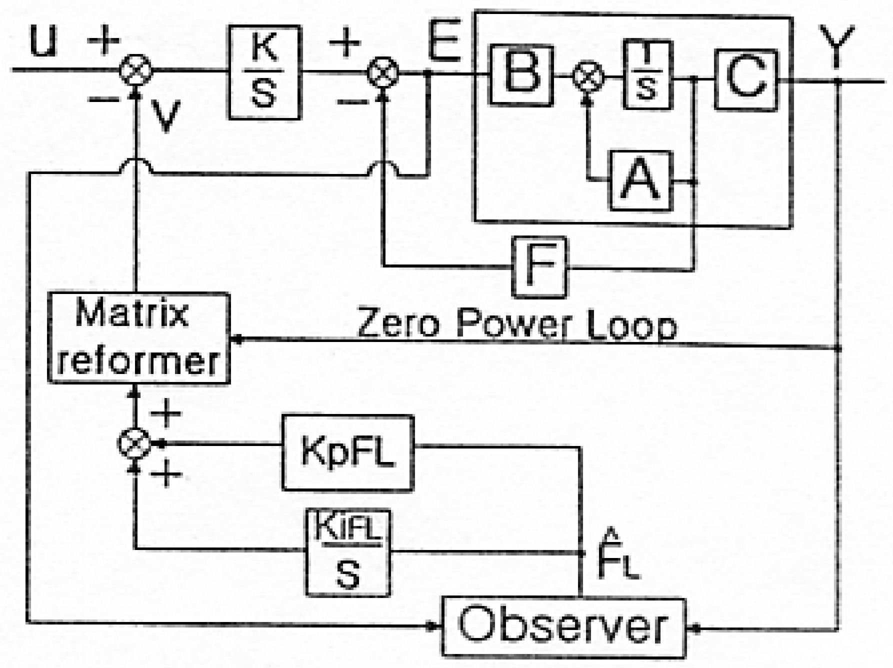


Fig. 2. The block diagram of zero power control with load observer

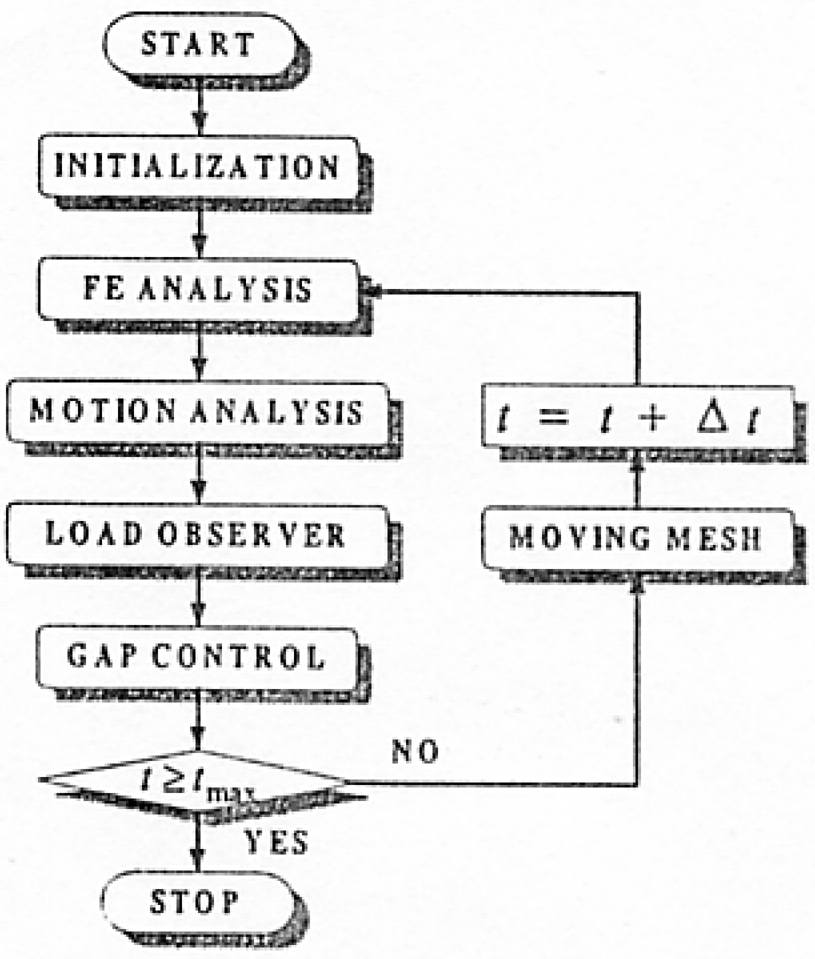
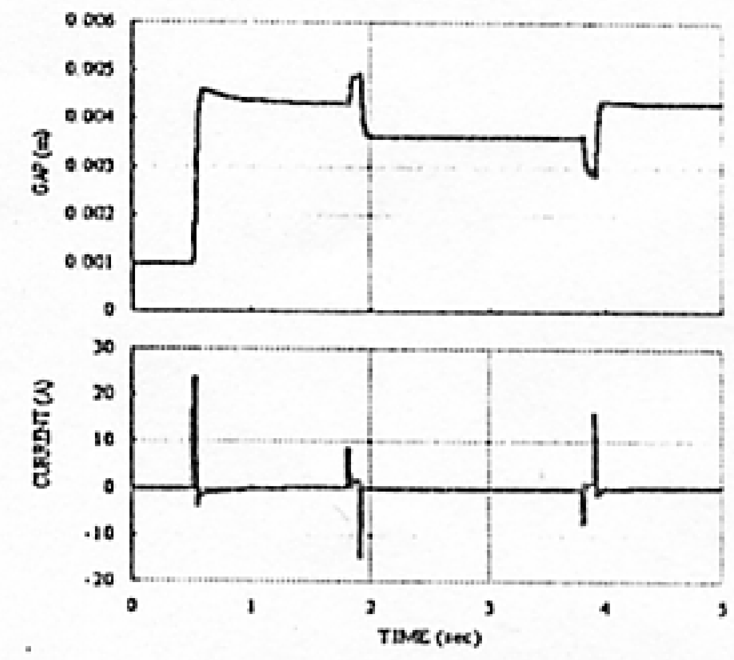
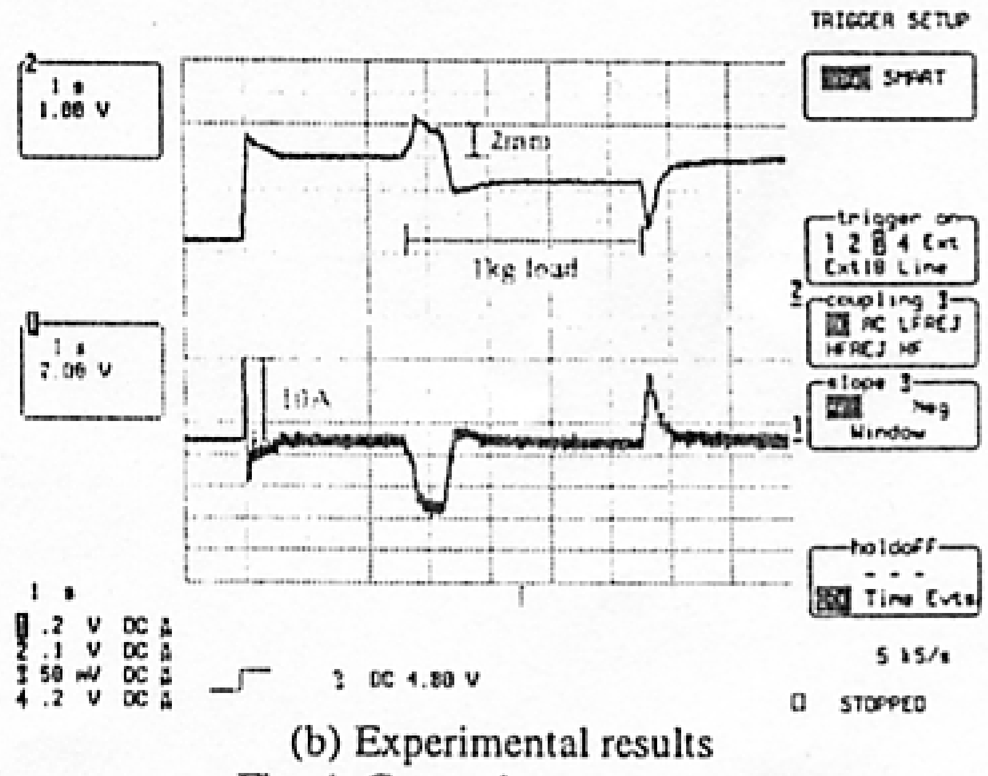


Fig. 3. Flow chart of the analysis



(a) FEM simulation results



(b) Experimental results

Fig. 4. Gap and current output