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Design a linear motor absorber

Chi-Shen Chang[a)]
Department of Mechanical Engineering, National Chiao Tung University, 1001 Ta Hsueh Road, Hsinchu 30010, Taiwan, Republic of China and Opto-Electronics and Systems Laboratories, Industrial Technology Research Institute, 195 Section 4, Chung Hsing Road, Chutung, 31040, Taiwan, Republic of China

Tzong-Shi Liu
Department of Mechanical Engineering, National Chiao Tung University, 1001 Ta Hsueh Road, Hsinchu 30010, Taiwan, Republic of China

Shir-Kuan Lin
Department of Electrical and Control Engineering, National Chiao Tung University, 1001 Ta Hsueh Road, Hsinchu 30010, Taiwan, Republic of China

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This paper raises a valid method to design a linear motor which serves as active dynamic vibration absorber to reduce disk drives vibration at multiple speeds. A better linear motor performance, such as lower consumption energy and higher electrical efficiency, can be achieved by tuning the diameter of a winding coil, the thickness of the magnet, and the winding spaces in a linear motor absorber. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2176893]

I. INTRODUCTION

A linear motor is usually used in occasions where rapid and precision motions in translation are required. The linear motor has many applications, such as in the sled motion in magneto-optical (MO) drives, the focusing of camera lens, and robots. Generally, optical disk drives have to make a disk spin at multiple speeds by different read/write conditions. However, the passive vibration absorber in current optical disk drives only suppresses vibration at a specific rotating speed and may excite vibration at other speeds. Vibration at multiple rotating speeds may become one of the serious problems to be resolved as storage capacity increases. Thus, an innovative dynamic vibration absorber, which is designed based on the linear motor, is called a linear motor absorber. Using this linear motor absorber, it has a good absorbency for reducing disk drives vibration at multiple speeds.[1] Most works concerning linear motors considered mainly the dynamic response.[2] This paper raises a valid method to design a linear motor absorber acting as dynamic absorber. A better linear motor absorber performance, such as higher vibration absorbency, low power consumption, and higher electrical efficiency, can be achieved by turning the diameter of a winding coil, the thickness of the permanent magnet, and the winding spaces in a linear motor absorber. In design procedure it also needs to consider the limit of currents and voltages in this system.

II. MODELING

Figure 1 depicts a primary system with mass m_1, stiffness k_1, and damping c_1 coupled with a linear motor absorber with mass m_2, stiffness k_2, and damping c_2. The unbalanced force $F(t)$ acts on feeding deck. The linear motor absorber structure is shown in Fig. 2. The magnetic field is produced by permanent magnets placed on both sides of a permeable material such as silicon steel or low-carbon steel. The Lorentz forces push a moving coil when it is electrified in the magnetic field. The moving part consists of moving coil and added mass such as absorber mass. Two guide rods constrain the moving coil in straight line motion. Springs behave like stiffness and damping of a passive absorber for propping the absorber mass. For reducing vibration of a disk drive, prescribing control system input that consists of multiple disk speeds and the moving coil displacement leads to the required electrical voltages in linear motors. The design problem of a linear motor absorber restricted in limited space can be formulated to find the diameter of one coil in the windings ϕ and the thickness of paramagnet l_m. Assume the gap between windings and permanent magnets or steels being invariable, so using

$$l_m + l_w = l_0 \tag{1}$$

denotes limited space, where l_0 is a constant and l_w is the thickness of windings. Indeed, the magnetic field in the linear motor is constructed by determining l_m. Furthermore, the number of turns of the moving coil N can be estimated as

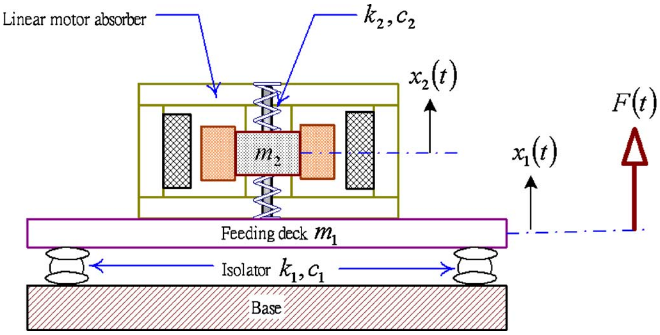

FIG. 1. (Color online) System model of linear motor absorber adhere to feeding deck.

[a)] Electronic mail: chishen@itri.org.tw

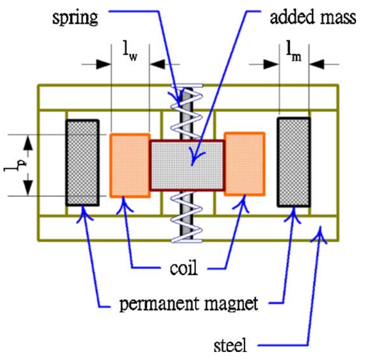

FIG. 2. (Color online) Structure of the linear motor absorber.

$$N \approx \text{round}\left(\frac{l_w}{\phi}\right)\text{round}\left(\frac{l_p}{\phi}\right), \tag{2}$$

where l_p is the width of the windings and N is a function of ϕ and l_m.

The design philosophy for a high quality linear motor absorber used in optical disk drives is to define two performance indexes: the consumption energy E_0 and the electrical efficiency η. The electrical efficiency is used to estimate the copper loss of the linear motor absorber. These indexes are formularized as follows:

$$E_0(l_m,\phi) = \int_0^{t_\nu} i(t)V(t)dt, \tag{3}$$

$$\eta(l_m,\phi) = \frac{E_0(l_m,\phi) - \int_0^{t_\nu} i^2(t)R(l_m,\phi)dt}{E_0(l_m,\phi)}, \tag{4}$$

where i is the current of the windings per turn, V is the terminal voltage, R is the coil resistance, and t_v is the variation time. Equations (3) and (4) show that E_0 and η are functions of l_m and ϕ. The design goal is to decrease E_0 and to increase η to obtain a better linear motor absorber under regular current and voltage.

It is known[1,3] that the dynamic equations of the linear motor can be written as

$$V(t) = i(t)R(l_m,\phi) + L(l_m,\phi)\frac{di(t)}{dt} + K_\nu(l_m,\phi)[\dot{x}_2(t) - \dot{x}_1(t)], \tag{5}$$

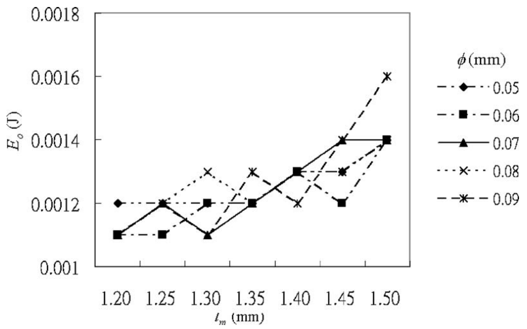

FIG. 3. E_0 vs l_m and various values of ϕ.

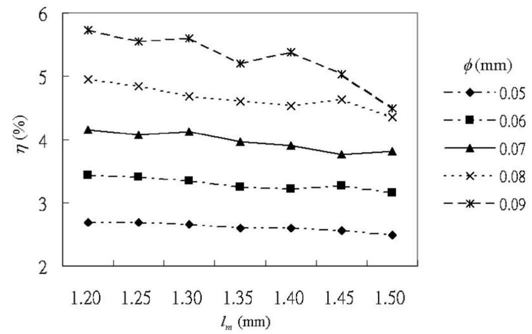

FIG. 4. η vs l_m and various values of ϕ.

$$m_1\ddot{x}_1(t) + c_1\dot{x}_1(t) + c_2[\dot{x}_1(t) - \dot{x}_2(t)] + k_1x_1(t) + k_2[x_1(t) - x_2(t)] + iK_f(l_m,\phi) = F(t) = p\omega^2e^{j\omega t}, \tag{6}$$

$$m_2\ddot{x}_2(t) + c_2[\dot{x}_2(t) - \dot{x}_1(t)] + k_2[x_2(t) - x_1(t)] - i(t)K_f(l_m,\phi) = 0, \tag{7}$$

where p is the unbalance, L is the coil inductance, K_v is the voltage constant, and K_f is the force constant. If p, K_f, m_1, m_2, c_1, c_2, k_1, k_2, and ω are known, i, $\dot{x}_1$, and $\dot{x}_2$ can be obtained by solving Eqs. (6) and (7) and the equations of Chang *et al.*[1] If R,L, and K_v are known, $V(t)$ can be obtained by solving the Eq. (5). Thus, the indexes E_0 and η can be evaluated by Eqs. (3) and (4).

It was pointed out[4] that the value of K_v is equal to K_f in the MKS unit. In the design procedure, K_v, K_f, and L can be predicted by the finite element method. From Ohm's laws, the coil resistance can be estimated as

$$R(l_m,\phi) = \frac{1}{\sigma}\frac{l_t(l_m,\phi)}{\pi\phi^2/4}, \tag{8}$$

where σ is the conductivity of the windings and l_t is the total length of the windings. It should be remarked that K_v, K_f, R, and L are all functions of l_m and ϕ, i.e., they vary with l_m and ϕ.

III. DESIGN PROCEDURE AND ANALYSIS

Given that passive absorber frequency ω_2 is 10 000 rpm, unbalanced force frequency ω is 6000 rpm, the maximum of V and i are, respectively, 25 V and 0.23 A, l_0 is 1.9 mm, m_1 is 185.26 g, c_1 is 1.1509 kg/s, k_1 is 10145 N/m, m_2 is 10 g, and c_2 is 1.0685 kg/s. As l_m and ϕ vary, the finite element

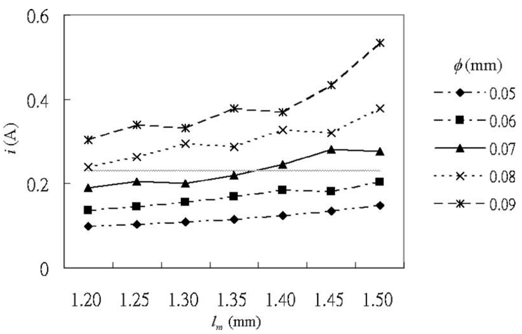

FIG. 5. i vs l_m and various values of ϕ. The small dotted line is the regular current (0.23 A).

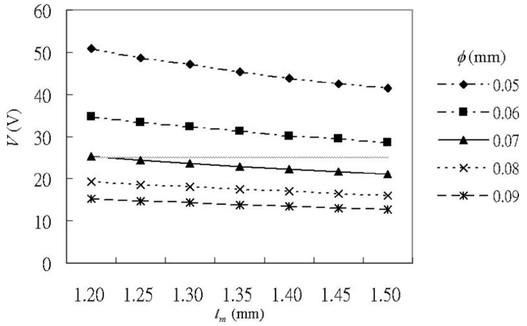

FIG. 6. V vs l_m and various values of ϕ. The small dotted line is the regular voltage (25 V).

method and Eq. (8) are used to obtain K_f, K_v, R, and L.The value are substituted into Eqs. (5)–(7) and the equations of Chang *et al.*[1] to solve for $V(t)$ and $i(t)$, which allow us to evaluate E_0 and η by Eqs. (3) and (4). The relations of E_0, η, i, and V to l_m and ϕ are then obtained and shown in Figs. 3–6, respectively.

Figures 3 and 5 reveal that E_0 and i decrease with the decrease of both l_m and ϕ. It follows from Fig. 4 that η increases with the decrease of l_m or with the increase of ϕ. Figure 6 reveals that V decreases with the increase of both l_m and ϕ. The maximum efficiency is $\eta=5.73\%$ when $l_m=1.2$ mm and $\phi=0.09$ mm, but the current is 0.3039 A which is larger than regular value 0.23 A. The requirement of low E_0 and high η under regular current and voltage asks us to choose $l_m=1.3$ mm and $\phi=0.07$ mm. This design choice has $E_0 \approx 0.0011$ J and $\eta \approx 4.13\%$.

IV. CONCLUSIONS

This paper proposes a design philosophy for a linear motor used in the dynamic vibration absorber system of an optical drives. Two performance indexes are defined for design goals of low the consumption energy E_0 and high electrical efficiency under both regular current and voltage. A design procedure is proposed to achieve these goals by adjusting the diameter of a winding coil, the thickness of the magnet, and the winding spaces in a linear motor. An example of designing linear motor absorber is also presented.

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