Principles of Active Vibration Control: Electro-magnetic

Introduction:

This type of active suspension uses linear electromagnetic motors attached to each wheel. It provides extremely fast response, and allows regeneration of power consumed by utilizing the motors as generators. This nearly surmounts the issues of slow response times and high power consumption of hydraulic systems. It has only recently come to light as a proof of concept model from the Bose company, the founder of which has been working on exotic suspensions for many years while he worked as an MIT professor. Using an electromagnetic actuator shown in Fig. 8.50, kinetic energy is converted to electrical energy, which is fed to the other motors where it is converted back into kinetic energy, which controls the dynamic system. By using power electronics devices in the electric circuits, good mechanical characteristics are achieved and the characteristics can be altered by switching the circuit. We are studying a methodology for implementing sophisticated motion and vibration control with a simple configuration by designing the distribution of electromagnetic actuators and power electronics devices according to the features and required characteristics of the target dynamic system.

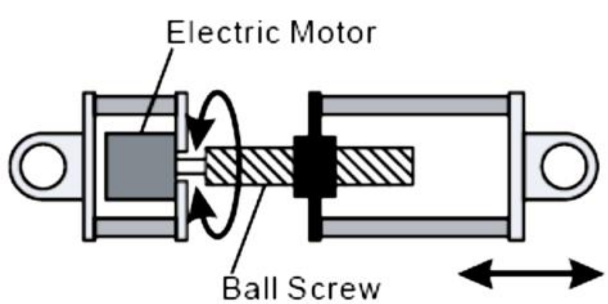

Fig. 8.50 Electromagnetic Actuator

In most dampers, the energy is converted into heat and dissipated without being used; in electromagnetic dampers, the dissipated energy can be stored as electrical energy and used later. The use of electromagnetic dampers in suspension systems has several benefits compared to hydraulic, pneumatic, or other mechanical dampers. Electromagnetic dampers can function simultaneously as sensors and actuators. The spring effect can be added to the system by means of electromagnets, powered by

Permanent Magnets (PMs). Moreover, electromagnetic dampers can work under very low static friction. Here, the damping coefficient is controlled rapidly and reliably through electrical manipulations.

Using electromagnetic dampers (composed of electromechanical elements), the kinetic energy of vehicle body vibration can be regenerated as useful electrical energy. The electromagnetic dampers (as actuators) have the potential to be used in active suspension systems. Automobiles and trucks have shock absorbers to damp out the vibration experienced due to roughness of the roads. However, energy in conventional shock absorbers gets dissipated as heat and not used in any way. Regenerative electromagnetic shock absorbers provide means for recovering the energy dissipated in shock absorbers. Electromagnetic shock absorbers for potential use in vehicles are fabricated and tested for their performance.

The Electromagnetic damper (ED) consists of two main parts: a fixed stator and a moveable slider as shown in Fig. 8.51. In the stator, windings (and potentially position and temperature sensors) are integrated into a metal cylinder. On the other hand, the mover (slider) utilizes Permanent Magnets (PMs) that are screwed to an aluminum rod via iron spacers (pole pieces). The proposed regenerative damper converts the vibrations of the body mass into a useful electrical energy, compensating the high energy consumption in active suspensions. The damper is also cost effective, consisting of several PMs in combination with electromagnets as major components and a straightforward fabrication. This cost-effective, regenerative ED is based on the concept of a tubular, linear, brushless dc motor, and can be used in passive, semi-active, and active operating modes.

In the passive/semi-active modes, the ED operates as a generator, converting the vibration of the vehicle body to electrical energy, where the motional electromotive force (emf) is induced in the coils due to the relative motion of the mover and stator. The generated emf creates an opposing force that is proportional to the velocity of the mover, causing a viscous damping effect. On the other hand, in the active-mode, the coils are energized so that the ED can operate as an actuator. The ED design is started with the optimal topology selection, and continues with a prototype ED design procedure to achieve the maximum thrust force density, utilizing analytical models derived from magnetic circuit principles. Next, after a prototype ED is fabricated, experiments are carried out in the passive mode to verify the accuracy of the numerical model.

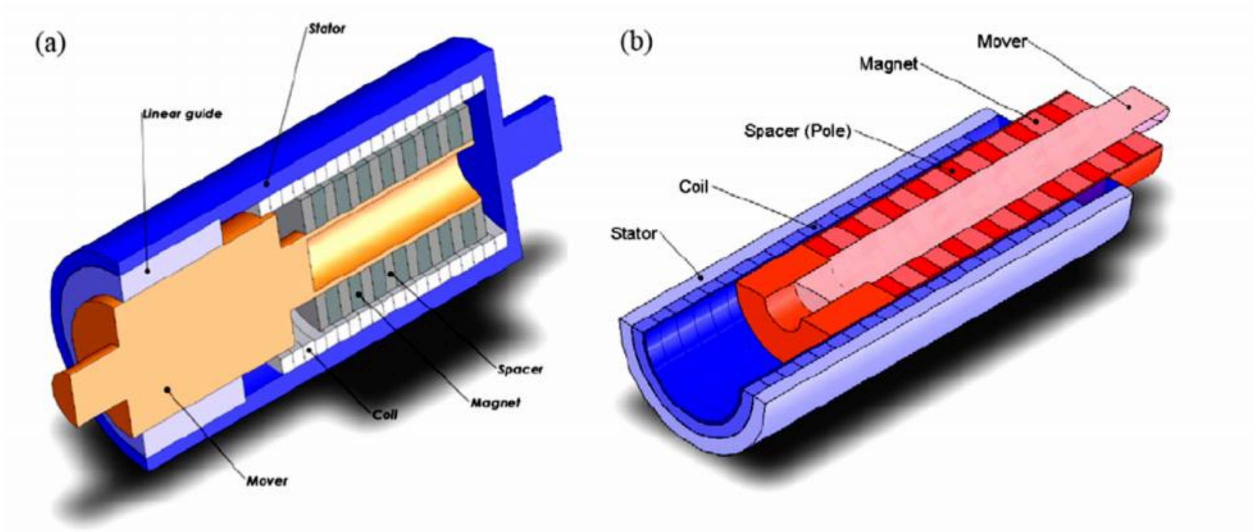

Fig. 8.51 Electromagnetic damper with two configurations: (a) Annularly shaped magnets supported by a non-magnetic rod (b) magnets fastened together in a non-magnetic tube. [Babak Ebrahimi, 1999]

As shown in Fig. 8.51, there are two options respecting the manufacturing issues. Fig. 8.51 (a) depicts the annularly shaped magnets, supported by a non-ferromagnetic rod, while Fig. 8.51 (b) shows another design with magnets fastened together in a non-magnetic tube, which is sliding on another tube shielding the stator coils. The latter configuration limits the minimum size of the effective air-gap to the sum of those two tubes' thicknesses; however, it is easier in terms of manufacturing while saving the weight and volume, as the former design requires additional linear guides. The latter configuration (as shown in Fig. 8.51 (b)) is selected for ease of manufacturing and to reduce the total weight, volume and cost. The magnetic circuit is also a basic requirement just to improve the damping performance as it is constrained by its volume. Design parameters are taking into consideration as the dimensions of the magnets and coils and Fig. 8.52 shows the lumped model of the proposed electromagnetic shock absorber and the equivalent magnetic circuit. The direction of the flux density is also shown in the figure.

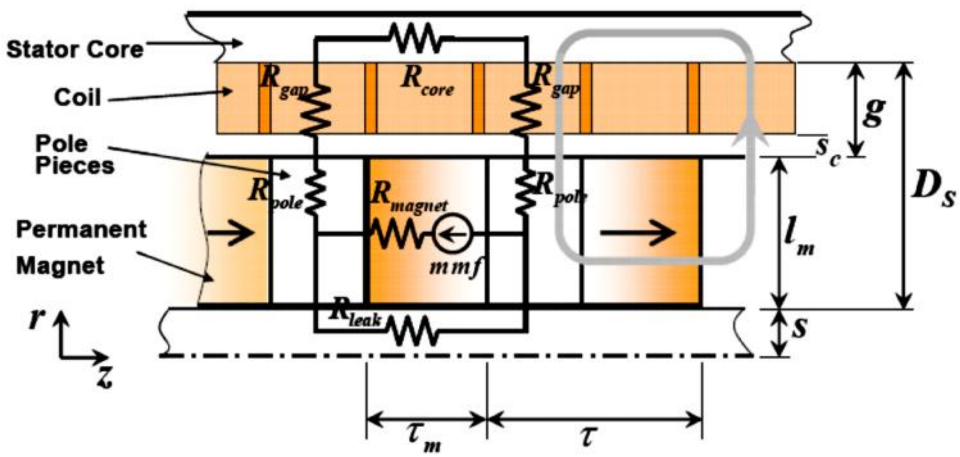

Fig. 8.52 Configuration of the linear interior PM motor and the equivalent magnetic circuit [Babak Ebrahimi, 1999]

A magnetic circuit is a closed path of magnetic flux, and contains ferromagnetic materials and field sources such as permanent magnets and coils. For one pole pair, the iron core has an infinite magnetic permeability without any leakage of flux in connecting rod, so its saturation and reluctance can be neglected. Consider a circuit with *m* segments with different permeabilities;

$$\oint \boldsymbol{H} \cdot dl = \sum_{i=1}^{m} H_i l_i = nI \tag{8.18}$$

$$\sum_{i=1}^{m} \Re_i \Phi_i = \sum_{k=1}^{N} \mathfrak{M}(k) \, , \tag{8.19}$$

where $\boldsymbol{R_i = l_i / \mu_i A_i}$ is the reluctance of the *ith* element, A_i is the cross-section area of element, ϕ_i is magnetic flux in the element, and $m\ (k)$ is known as the magnetomotive force (mmf) for the *kth* source (when there are N sources). $m = ni$ for a n-turn coil, and $m = H_c\, l_m$ for a magnet with length l_m and coercivity H_c .

$$\left(R_{mag} + 2R_{gap}\right)\phi_g = H_c\tau_m = \frac{B_{rem}}{\mu_{rec}}\tau_m ,$$

(8.20)

where H_c, B_{rem}, and μ_{rec} are the coercive magnetic field intensity, remanent flux density, and recoil permeability of the magnets, respectively, and ϕ_g is the air-gap magnetic flux. The magnet and gap reluctances are;

$$R_{mag} = \frac{\tau_m}{\mu_{rec}\pi\left((l_m + s)^2 - s^2\right)},$$

$$R_{gap} = \frac{g}{\mu_0\pi 2(l_m + s + g/2)\left(\dfrac{\tau - \tau_m}{2}\right)}.$$

(8.21)

The air-gap magnetic flux density is mathematically expressed as

$$B_g = \frac{B_{rem}\tau_m\mu_0 H_c}{\left(2gB_{rem} + \tau_m\mu_0 H_c\dfrac{A_g}{A_m}\right)} .$$

(8.22)

The induced emf in the *ith* phase depends on the flux linkage in the phase due to the magnets (λ_{PM}), and is

$$E = \frac{d\lambda_{PM}}{dt} = \frac{d\lambda_{PM}}{dz}\frac{dz}{dt},$$

$$\lambda_{PM} = N\phi_g \cos((\pi/\tau)z). \tag{8.23}$$

$$E_1 = \frac{d\lambda_{PM}}{dt} = -N\phi_g \frac{\pi}{\tau}\sin\left(\frac{\pi}{\tau}z\right)\frac{dz}{dt}. \tag{8.24}$$

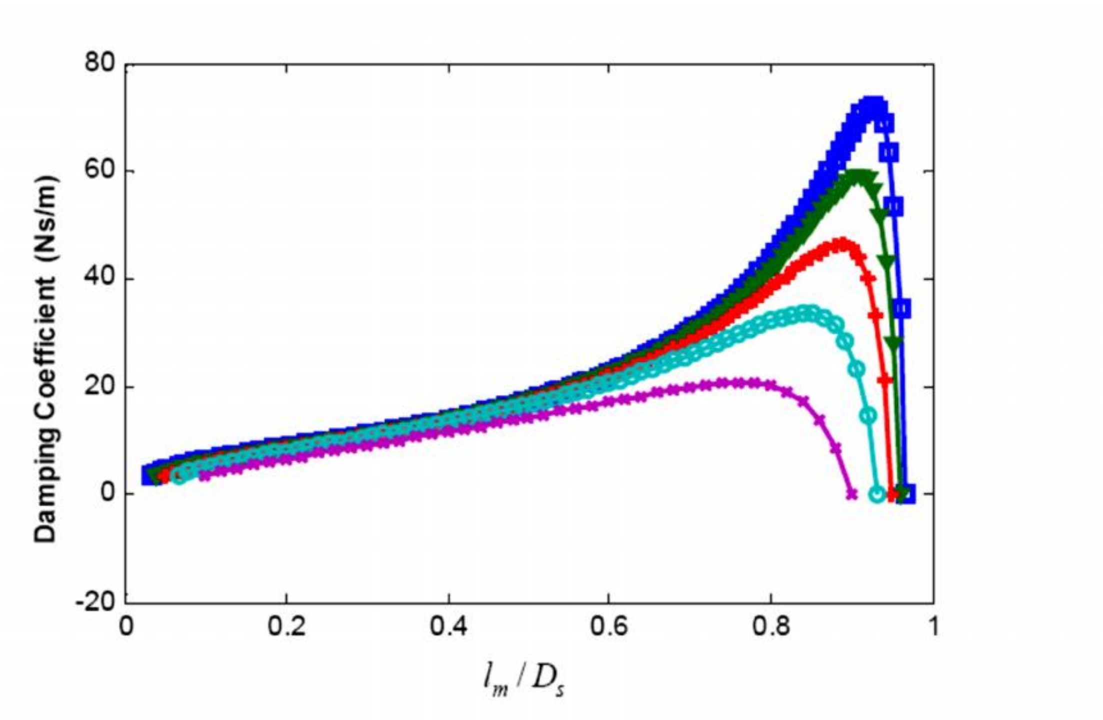

Fig. 8.53 Damping coefficient vs. normalized magnet length for different D_s values. —□—: D_s=30 mm, —∇— : D_s=25 mm, —+— : D_s=20 mm, —○— : D_s=15 mm, —×— : D_s=10 mm.

[Courtesy: Babak Ebrahimi, 1999]

ED can be configured in for experimentation as shown in Fig.8.54.

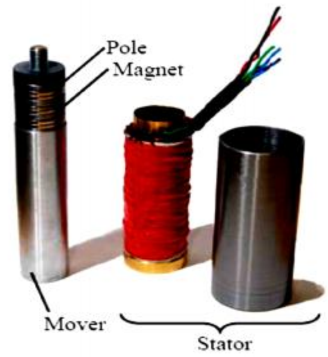

Fig. 8.54 ED design

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