Magnetic Mass Actuator (MMA)

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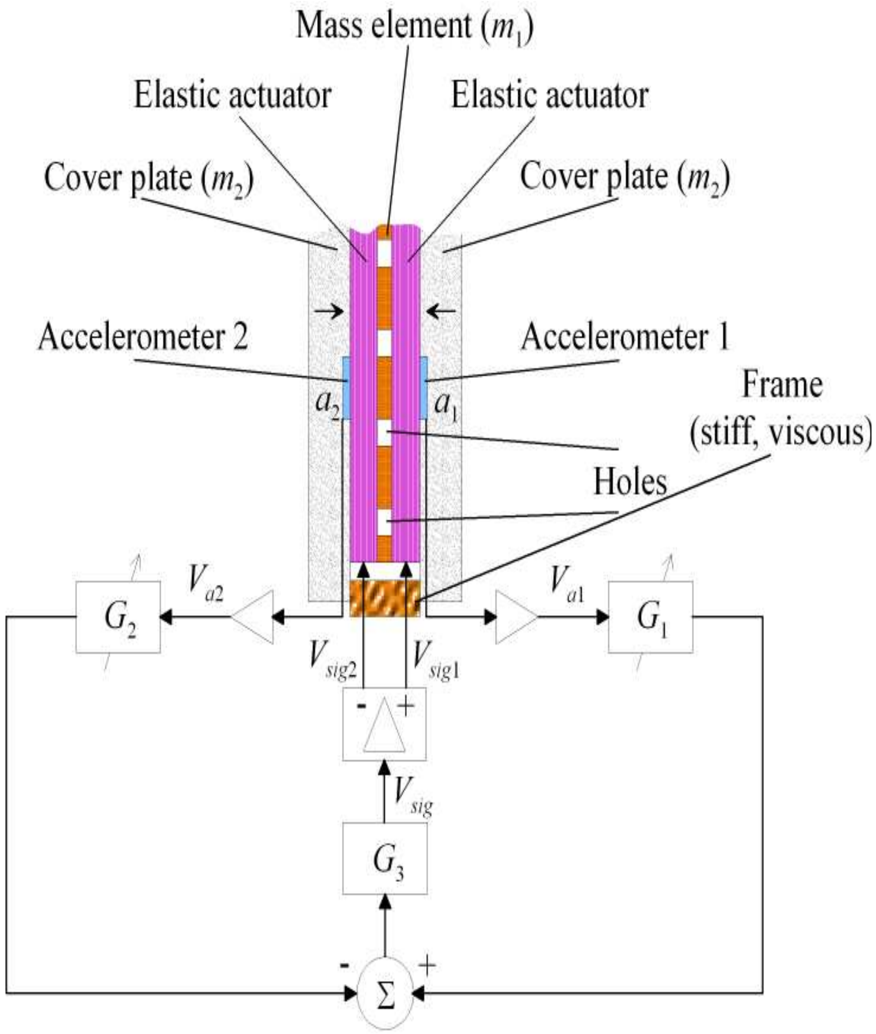
Business from technology

Background Study of Elastic Mass Actuator (EMA)

- EMA is large surface structural actuator to attenuate the lowest structural mode, which is the most efficient sound radiator of structural modes of panel like structures.
- In EMA, a mass plate is driven in between two electromechanical film (EMFi) layers.
- Electric interaction forces, which have been generated by supplying electric current to the EMFi layers, are controlled in such a way that the mass element tends to absorb vibrational energy, and thus, decrease the sound radiation of the panel on which it is attached.
- Unlike the active damping device (ADD), which works only on resonance; EMA is working quite well in a frequency band.



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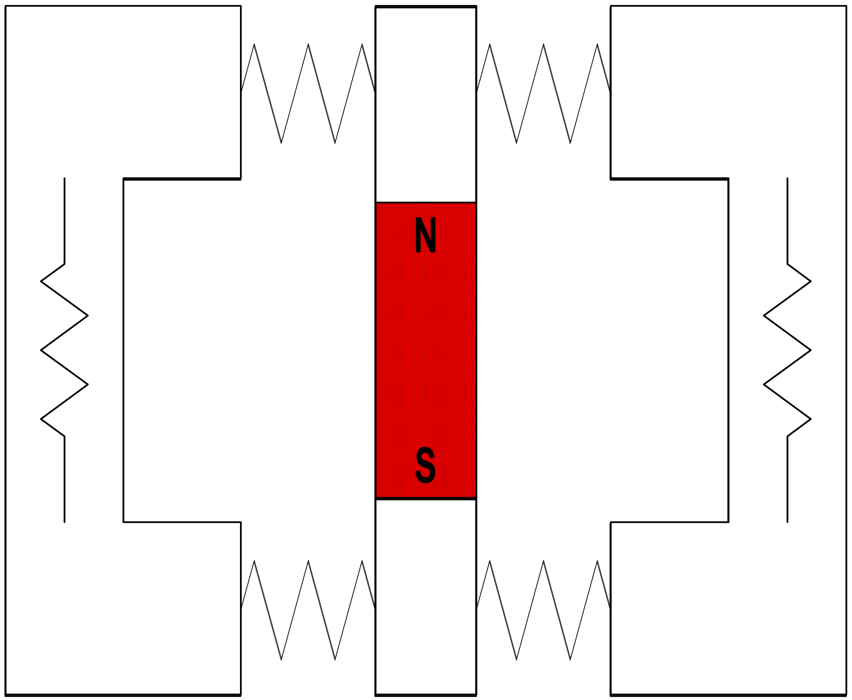
Disadvantage of EMA:

- The displacement amplitude of the mass plate is quite low.

Magnetic Mass Actuator (MMA)

- In MMA, a permanent magnet is driven in between two electromagnets by changing the polarity of the supply current.
- In principle, both the electric and magnetic fields develop the Maxwell stress tensor to develop the interaction forces.
- Therefore, we expect the MMA would work exactly like the EMA but with improved performance.



Schematic diagram of Magnetic Mass Actuator

Properties of electrodynamic actuator

- based on Lorenz Force

\+ Linear force-current ratio

\- Conductor occupies space in the air gap i.e., large air gaps so smaller force, $F \,\alpha\, B$

Properties of electromagnetic actuator

- based on unbalanced field distribution and Maxwell stress

\+ Good force capability due to small air-gap and $F \,\alpha\, B^2$

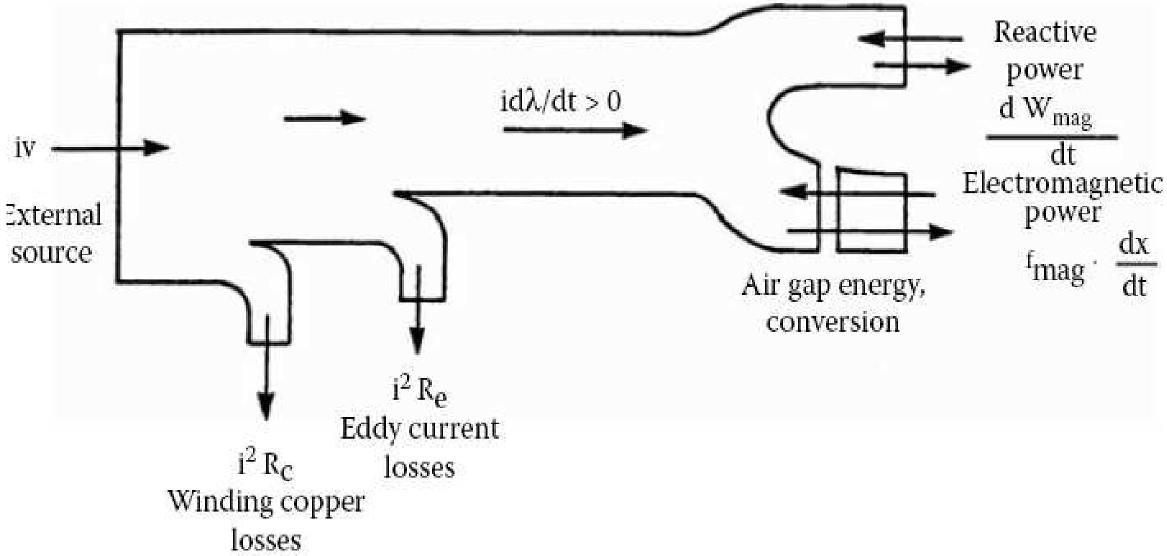
\- Non-linear force-current ratio

Electrical Equations

Electrical equations can be written as

$$V = iR_c + \frac{d\lambda_t}{dt}$$

$$\frac{d\lambda_t}{dt} = iR_e + \frac{d\lambda}{dt}$$



Also $\frac{d\lambda}{dt} = \frac{\partial\lambda(i,x)}{\partial i}\frac{di}{dt} + \frac{\partial\lambda(i,x)}{\partial x}\frac{dx}{dt}$

$$= L\frac{di}{dt} + \frac{\partial\lambda(i,x)}{\partial x}\frac{dx}{dt}$$

Therefore, the electrical equations can be written as

$$V = iR_c + iR_e + L\frac{di(t)}{dt} + \frac{\partial\lambda(i,x)}{\partial x}\frac{dx}{dt}$$

$$Vi = i^2R_c + i^2R_e + \frac{dW_{mag}}{dt} + F_{mag}\frac{dx}{dt}$$

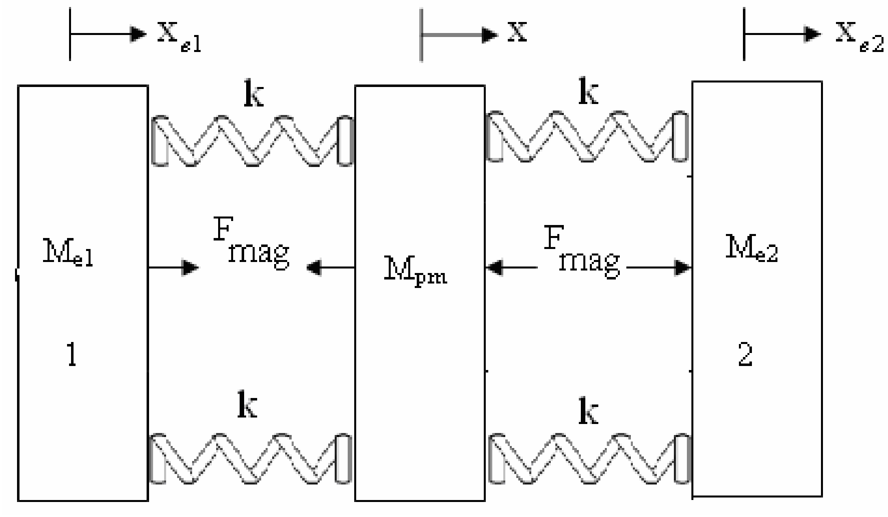
Mechanical Equations

Equations of motion can be written as

$$M_{e1}\ddot{x}_{e1} + 2k\left(x_{e1} - x\right) = F_{mag}$$

$$M_{pm}\ddot{X}_{pm} + 2k\left(x - x_{e1}\right) + 2k\left(x - x_{e2}\right) = -2F_{mag}$$

$$M_{e2}\ddot{x}_{e2} + 2k\left(x_{e2} - x\right) = F_{mag}$$



Assuming harmonic force and displacement, the mechanical equations of motion is

$$\begin{bmatrix} 2k - M_{e1}\omega^2 & -2k & 0 \\ -2k & 4k - M_{pm}\omega^2 & -2k \\ 0 & -2k & 2k - M_{e2}\omega^2 \end{bmatrix} \begin{Bmatrix} x_{e10} \\ x_0 \\ x_{e20} \end{Bmatrix} = F_0 \begin{Bmatrix} 1 \\ -2 \\ 1 \end{Bmatrix}$$

By knowing x_0 (from the plate vibration amplitude), F_0 can be calculated.

Electromechanical Equations

Electrical equation of the actuator is

$$V(t) = i(t)(R) + L\frac{di(t)}{dt} + \frac{\partial\lambda(i,x)}{\partial x}\frac{dx}{dt}$$

And the one degree of freedom mechanical equation of motion is

$$M\frac{d^2x}{dt^2} + kx = F(x)$$

For practical analysis, it is convenient to write the above equations in first order equations,

$$\frac{di(t)}{dt} = \frac{1}{L}\left[V(t) - i(t)(R + R_{coil}) - \frac{\partial\lambda(i,x)}{\partial x}v(t)\right]$$

$$\frac{dv(t)}{dt} = \frac{1}{m}F(i,x) - \frac{1}{m}kx$$

$$\frac{dx(t)}{dt} = v(t)$$

Analytical formulation

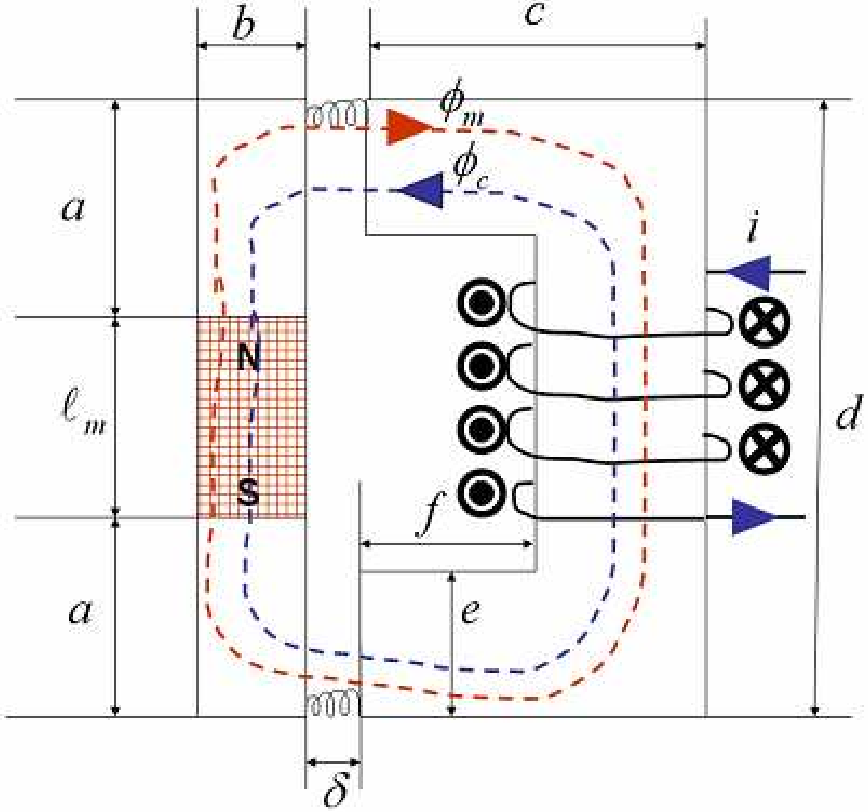
Assumptions: Leakage fields are not considered

$$\oint_C H \cdot dl = Ni \Rightarrow H_c l_c + 2H_g(\delta - x) = Ni \qquad (1)$$

$$B_m = \mu_R H_m + B_r \qquad (2)$$

$$B_g = \mu_0 H_g \qquad (3)$$

$$B_m S = B_g S \text{ (continuity of flux)} \qquad (4)$$



By solving the above equations, magnetic force between the PM and EM when they are attracting

$$F_{mag} = \frac{A_g}{\mu_0}\left[\frac{Ni\mu_0}{(A_g / A_c)(\mu_o / \mu) l_c + 2(\delta - x)} + \frac{A_m}{A_g}\frac{B_r}{\left[1 + 2(\mu_R / \mu_0)(A_m / A_g)\left(\frac{\delta}{l_m} - \frac{x}{l_m}\right)\right]}\right]^2$$

Calculation

Mechanical Force: By using upper table, mechanical force can be calculated as 100.1 N

M_{PM}	0.0225 kg
M_{e1}=M_{e2}	0.03 kg
f	500 Hz
x_0	0.001 m

δ	0.002 m
B_r	1.2 T
$\mu_R = \mu_0$	$4\pi \times 10^{-7}$
l_m	0.02 m
a	0.01 m
b	0.005 m
c	0.01 m
d	0.04 m
e	0.005 m
N	400
f	0.005 m

Magnetic force: By using the analytical formulation and Table 2, Magnetic force can be calculated as,

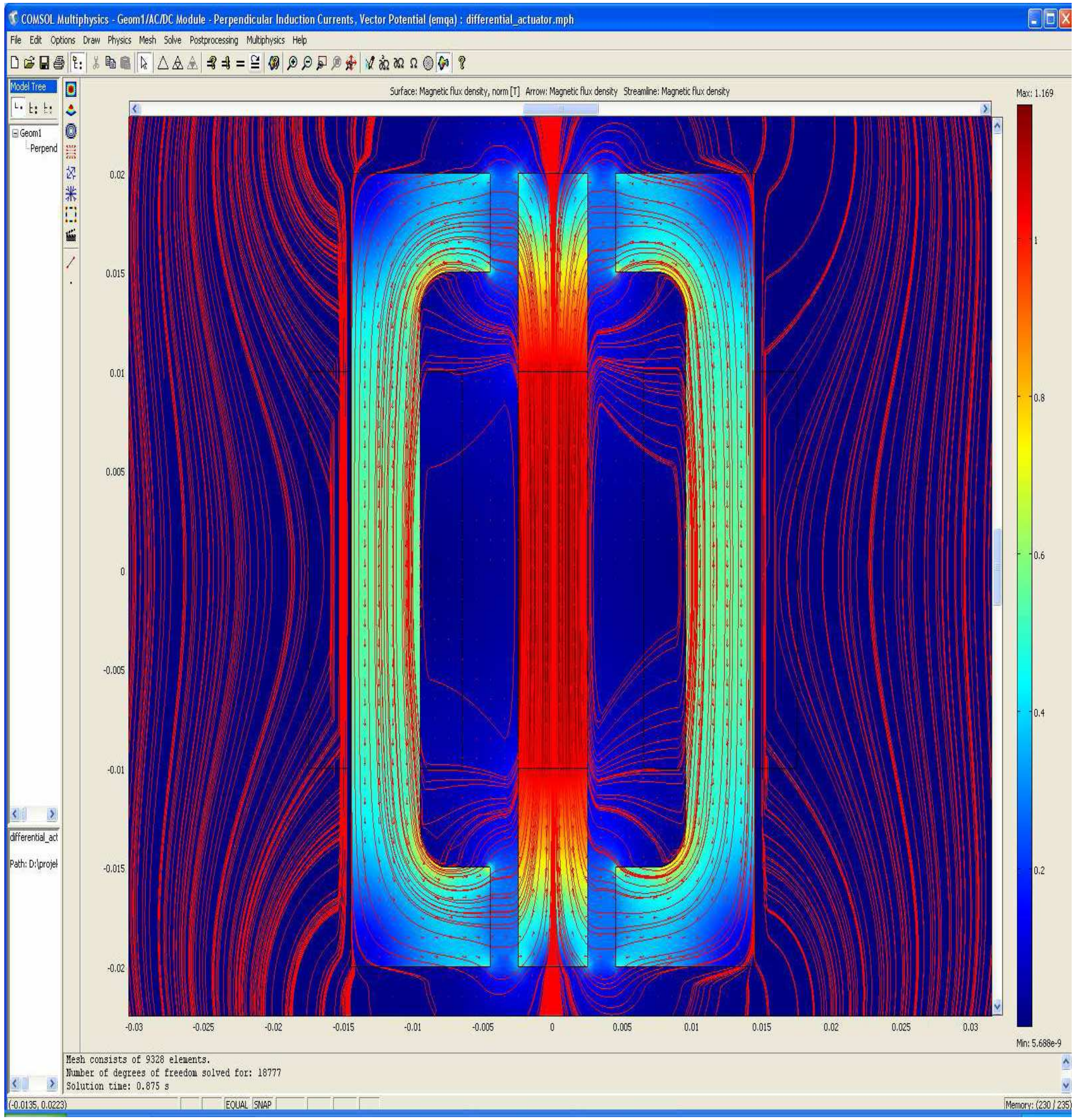
$$F_{mag} = 3.98 kN / m$$

$$B_g = 1T$$

COMSOl Multiphysics Model

Magnetic force is coming around 1700 N/(m.A) i.e, 10 cm axial length gives 170 N/A force

- The difference between the analytical result and numerical result is very well explained by the leakage fluxes.
- In bigger geometries flux is better concentrated on iron parts and leakage is reduced.



Conclusion

• A new Magnetic Mass Actuator has been proposed, which is able to move the middle mass plate with a greater magnitude than that of the Elastic Mass Actuator. However, the non-linearity relation between the force and current, and most importantly the magnetic losses needs to be taken care of.

Acknowledgements

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