Voice Coil Actuator

Suresh Devasahayam
Department of Bioengineering
Christian Medical College, Vellore

Lecture - Outline

- Magnetic Circuits
- Voice Coil

Force Actuators - Electromagnetic actuator

- EMF in a coil

$$V = -N \frac{d\phi}{dt}$$

- EMF in a moving conductor

$$V = -B u l$$

- Force on a conductor

$$F = B \; I \; l$$

- Magnetomotive force

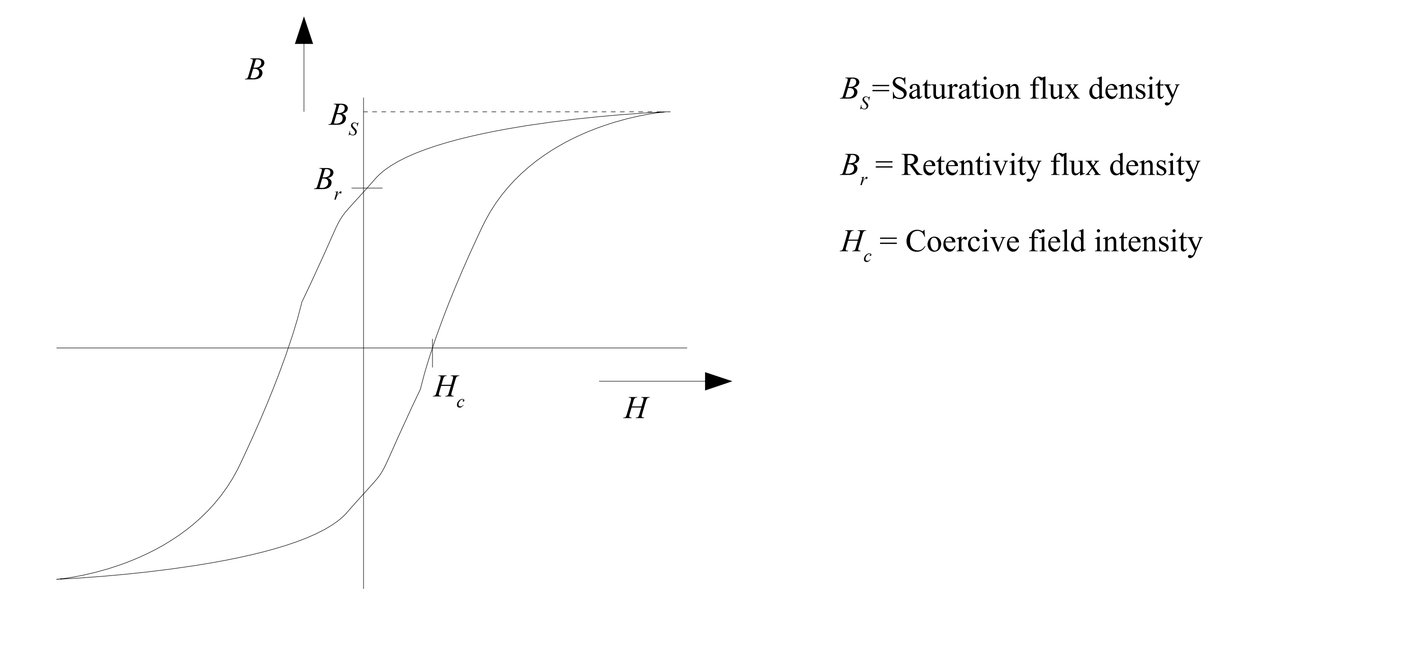
$$M = N \; I$$

Magnetic Circuit equivalent

Analogy between electric circuits and magnetic circuits

Electrical quantity			Magnetic quantity		
Name	Symbol	Unit	Name	Symbol	Unit
Electromotive force	V	V, (volts)	Magnetomotive force	M	Amp-turns
Electric field	$E = V/l$	V/m	Magnetic field intensity	$H = M/l$	Amp-turns/m
Current density	$J = I/A$	Amp/m^2	Magnetic flux density	B	Weber/m^2
Current	I	Amp	Magnetic flux	$\Phi = B.A$	Weber
Resistance	$R = V/I$ $R = \rho \frac{l}{A}$	Ω=Ohm =Volt/Amp	Reluctance	$R = M/\Phi$ 1. $R = \frac{1}{\mu}\frac{l}{A}$ 2. $R = \frac{H_c l_m}{B_r A_m}$	Amp-turns/Weber

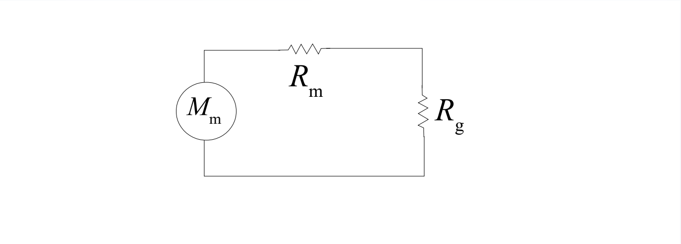
Field-Flux characteristics of a permanent magnet



- Permanent magnets B_rH_C =figure of merit (is large)
  - Steel, Ferrite: B_rH_C=9
  - Alnico: B_rH_C = 62400
  - Ne-Fe-B: B_rH_C=240000
- For electromagnets hysteresis (B_rH_C) should be small

Magnetic circuits

$$R_m = \frac{M_m}{\phi} = \frac{H_c l_m}{B_m A_m}$$

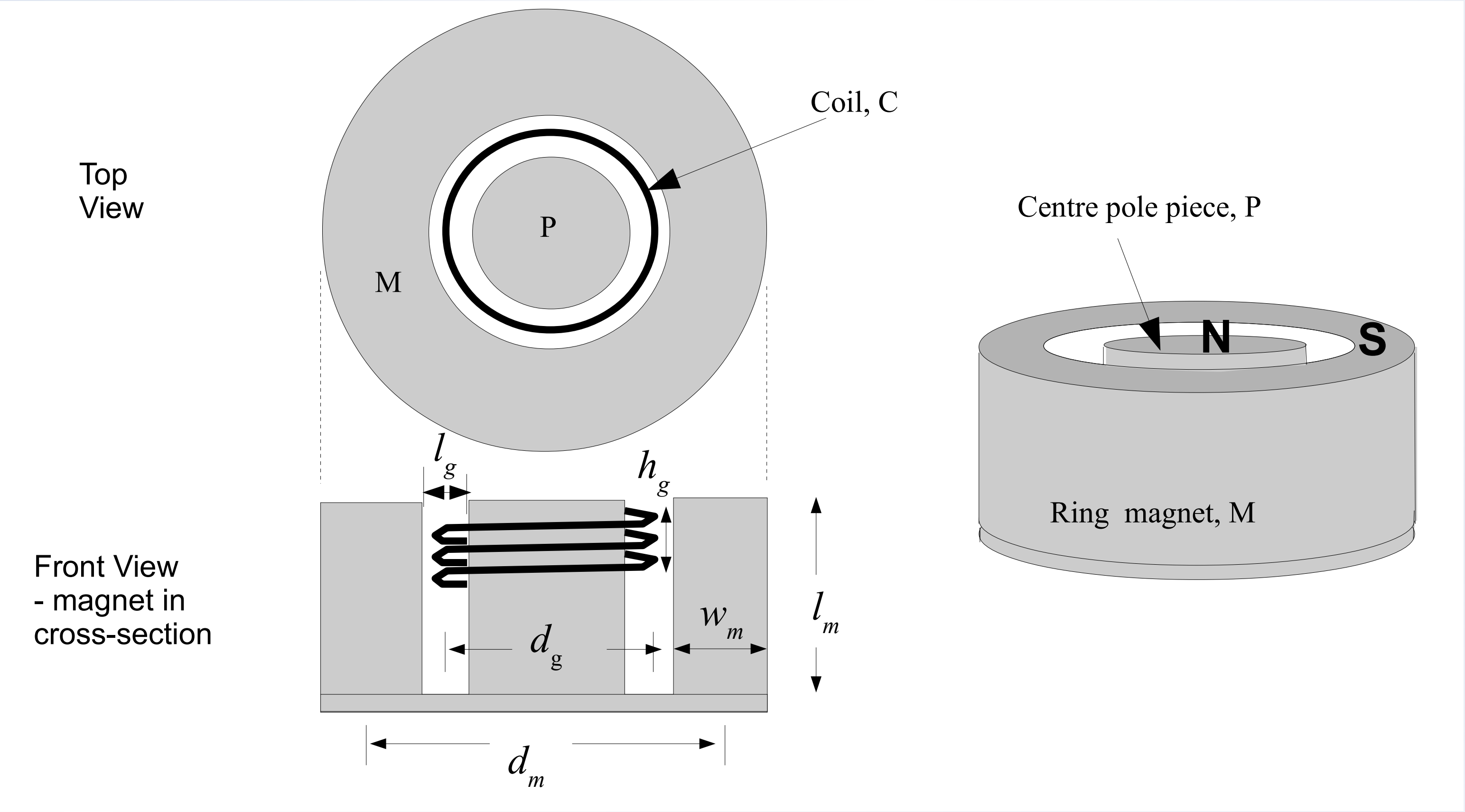


$$R_m = \frac{M_m}{\phi} = \frac{N I}{B_m A_m}$$

$$R_g = \frac{1}{\mu_o} \frac{l_g}{A_g}$$

$$\phi = \frac{M_m}{R_m + R_g} \cdot R_g$$

Voice coil - actuator



Magnetic circuit of voice coil

- Reluctance of magnet

$$R_m = \frac{H_c}{B_r}\frac{l_m}{A_m}$$

- Reluctance of pole piece

$$R_p = \frac{1}{\mu}\frac{l_p}{A_p} \qquad A_p = \pi d_1^2$$

- Reluctance of air gap

$$R_g = \frac{1}{\mu_o}\frac{l_g}{A_g} \qquad A_g = \pi d_g h_g$$

- Flux in air gap

$$\phi_g = \frac{H_c l_m}{R_m + R_p + R_g}$$

- Flux density in air gap

$$B_g = \frac{\phi_g}{A_g} = \frac{H_c l_m}{R_m + R_p + R_g}\frac{1}{A_g}$$

Force developed by the voice coil

- Force on the coil

$$F(t) = B_g \cdot I_c(t) \cdot l_c$$

- Laplace transform

$$F(s) = B_g \cdot l_c \cdot I_c(s)$$

- Length of conductor in coil

$$l_c = \pi d_g N$$

Electrical Excitation of voice coil

- Excitation voltage

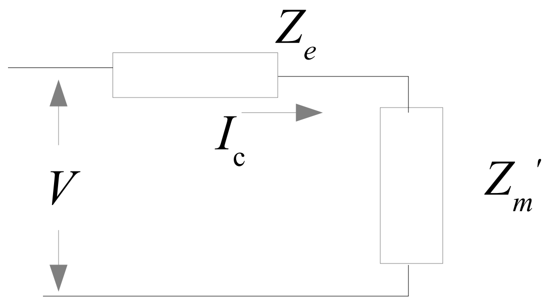
$$V_e(s) = I(s)\, Z_e(s)$$

$$V_b(s) = B_g l_c u(s)$$

- Back emf due to movement
- Total Applied Voltage

$$\begin{aligned} V(s) &= V_e(s) + V_b(s) \\ &= I(s) Z_e(s) + B_g l_c u(s) \end{aligned}$$

Electrical Equivalent



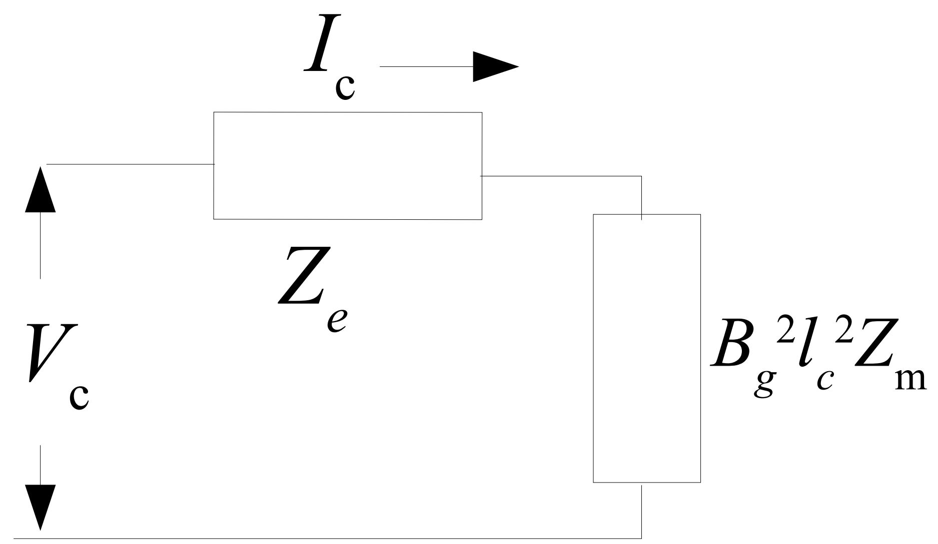
$$F(t) = m\dot{u}(t) + k_b u(t) + k_1 \int u(t)\,dt$$

$$u(s) = F(s) / [ms + k_b + k_1/s]$$

$$u(s) = \frac{B_g l_c I(s)}{ms + k_b + k_1/s}$$

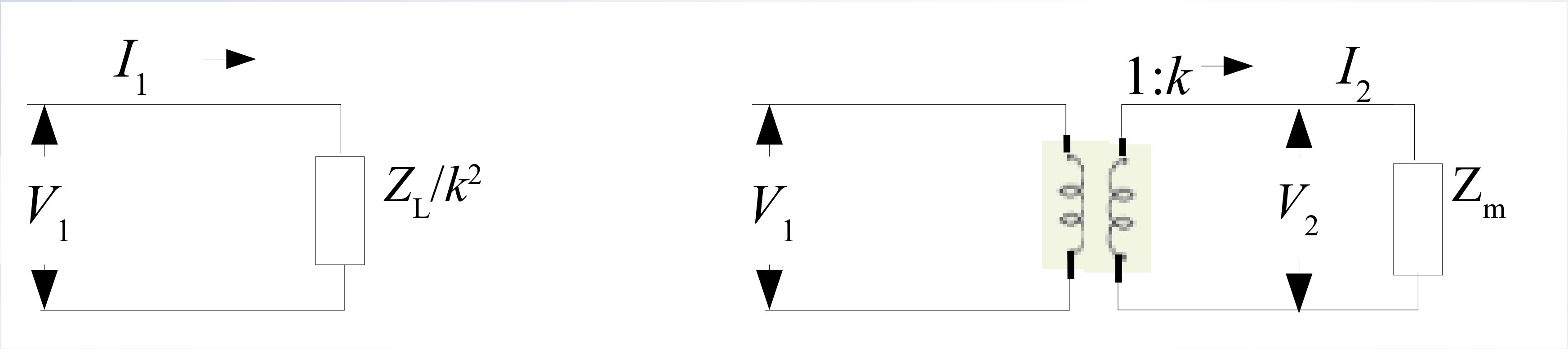
$$V(s) = V_e(s) + V_b(s) = I(s) Z_e(s) + I(s) \frac{B_g^2 l_c^2}{ms + k_b + k_1/s}$$

Equivalent Electrical Impedance due to mechanical components



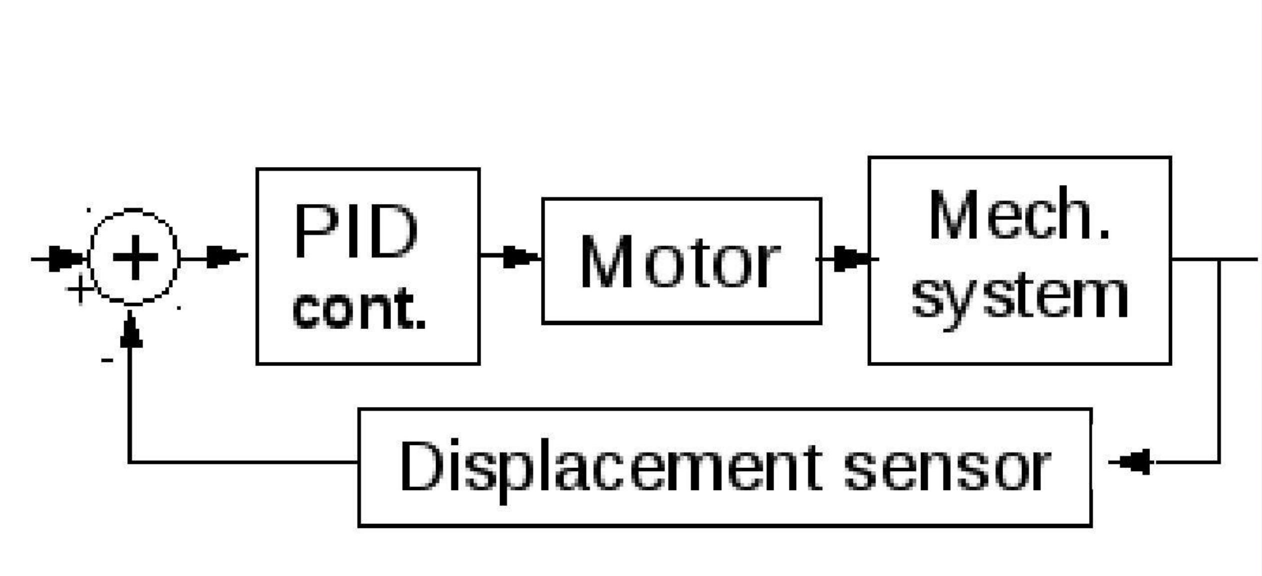
$$\frac{V_b(s)}{I(s)} = -B_g^2\, l_c^2\, Z_m(s)$$

Using a transformer representation

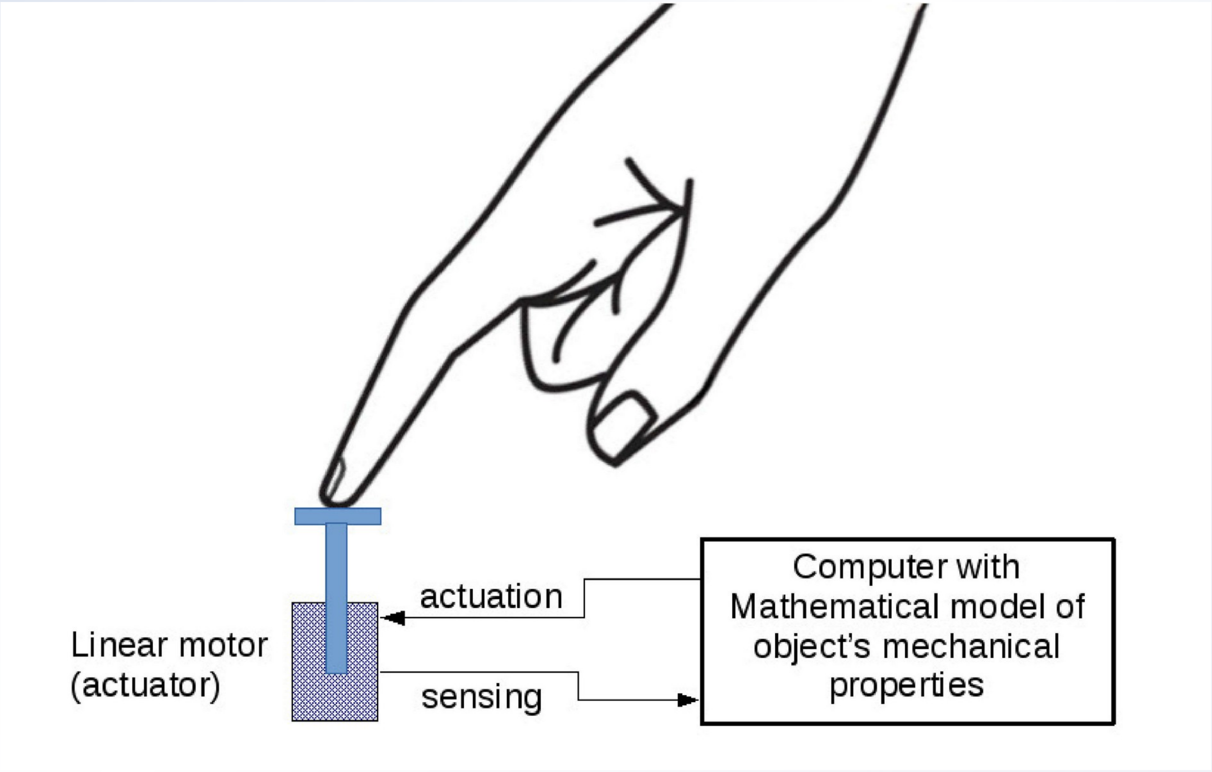


$$V_2 = k V_1 \;, \qquad I_2 = \frac{I_1}{k} \;, \qquad \frac{V_2}{I_2} = k^2 \frac{V_1}{I_1} \;, \qquad Z_L = \frac{V_2}{I_2} \;, \qquad \frac{V_1}{I_1} = \frac{Z_L}{k^2}$$

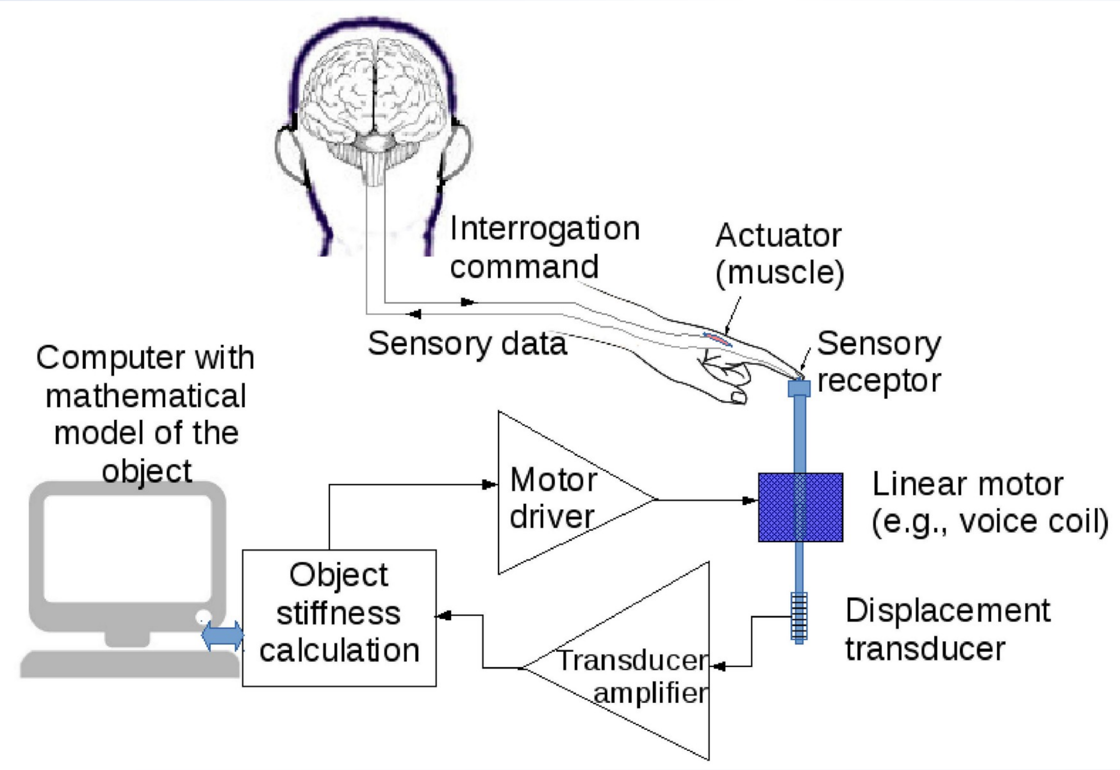
Servo Motor



Application of Servo motor in Haptics



Haptics – Feeling in Medical Devices



End of Lecture