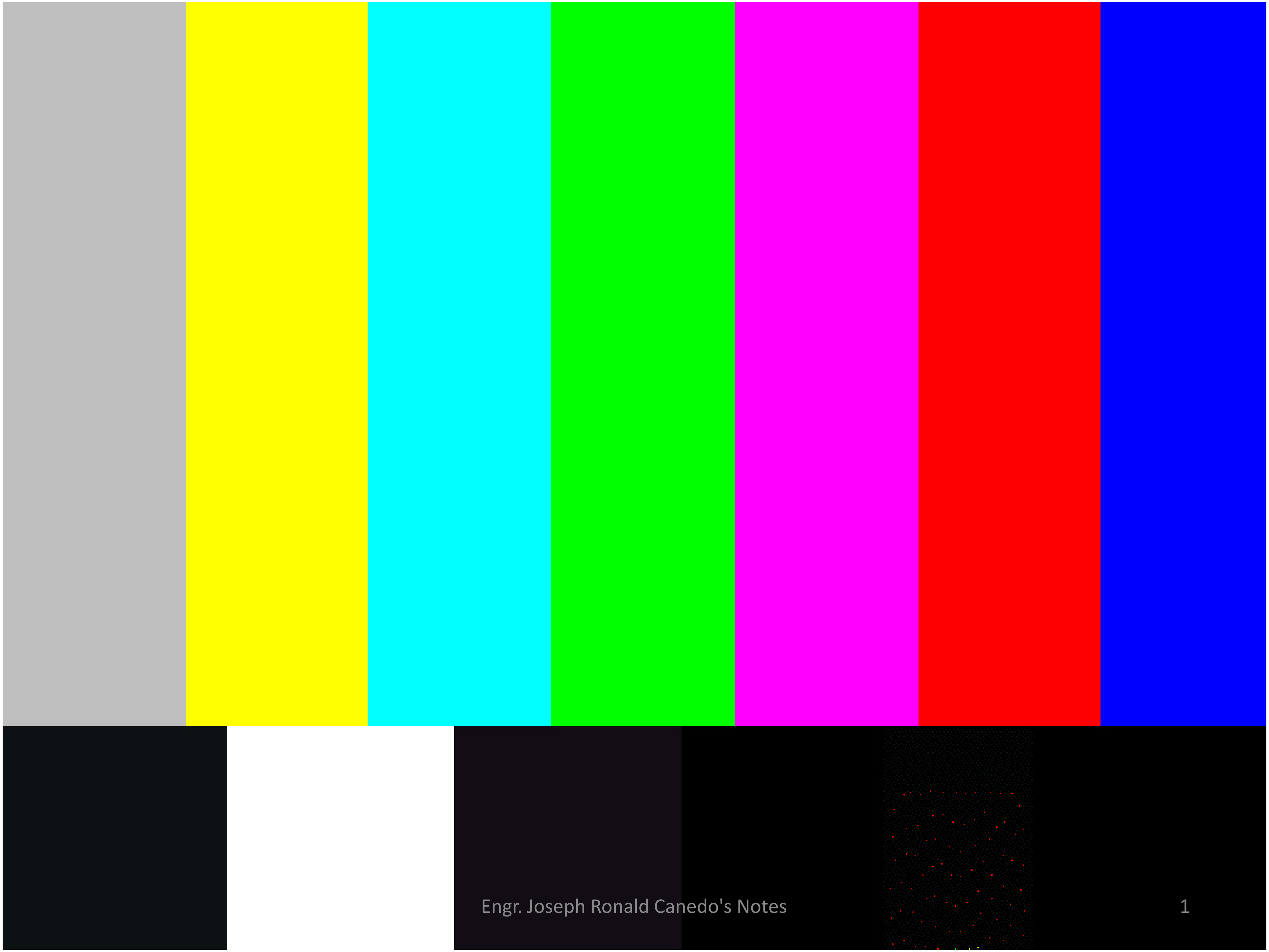

Modeling Electromechanical Systems

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Introductions

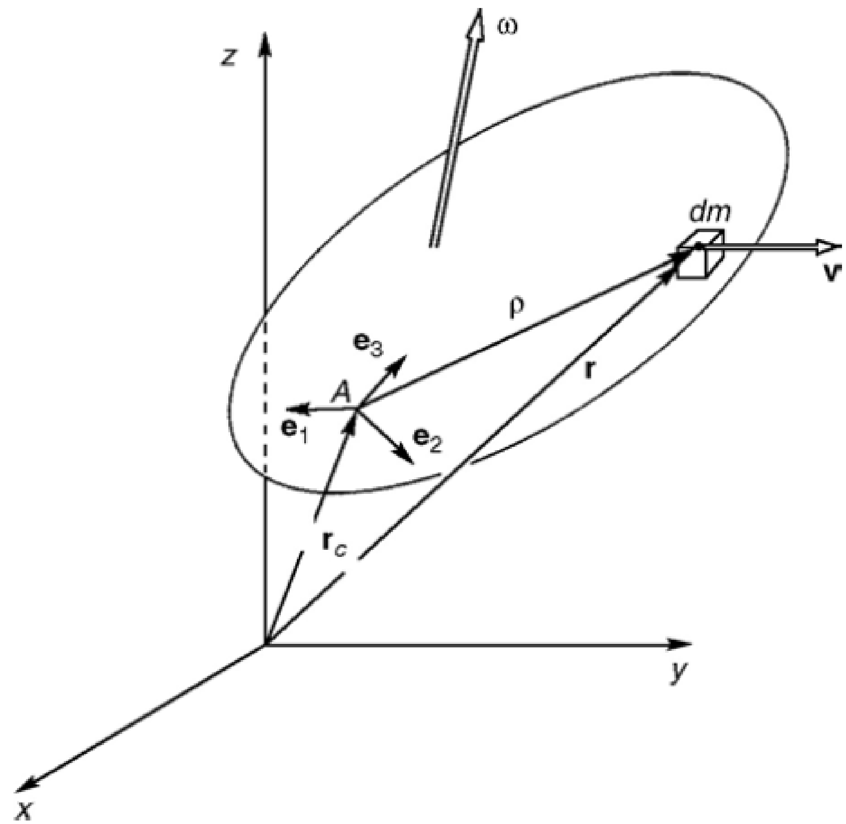
- Mechatronics describes the integration of mechanical, electromagnetic, and computer elements to produce devices and systems that monitor and control machines and structural systems.
  - VCRs
  - Automatic cameras
  - Automobile air bags
  - Cruise control devices
  - etc

Models for Electromechanical Systems

- Partial Differential Equations (PDEs) – is used as the fundamental equations of motion for physical continua. PDEs described dynamic behavior in both time and space.
  - The motions of strings
  - Elastic beams and plates
  - Fluid flow around and through bodies
  - Magnetic and electric fields require both the spatial and temporal information
- It will involve Navier-Stokes eqtns. of fluid mechanics and Maxwell-Faraday eqtns. of electromagnetics.
- Ordinary Differential Equations (ODEs)

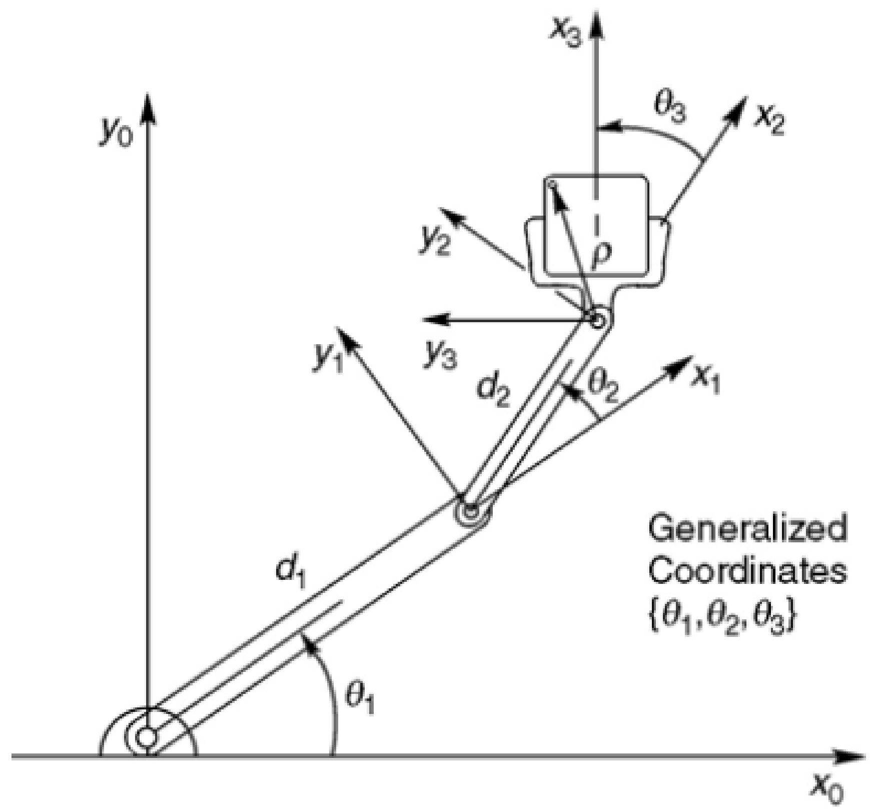
Rigid Body Models

- Kinematics of Rigid Bodies
  - Kinematics is the description of motion in terms of position vectors r, velocities v, acceleration a, rotation rate vector ω, and generalized coordinates $\{q_k(t)\}$ such as relative angular positions of one part to another in a machine.



Rigid Body Models

- Constraints and Generalized Coordinates
  - Machines are often collection of rigid body elements in which each component is constrained to have one degree of freedom relative to each of its neighbors.



Multilink Robotic
Manipulator Arm

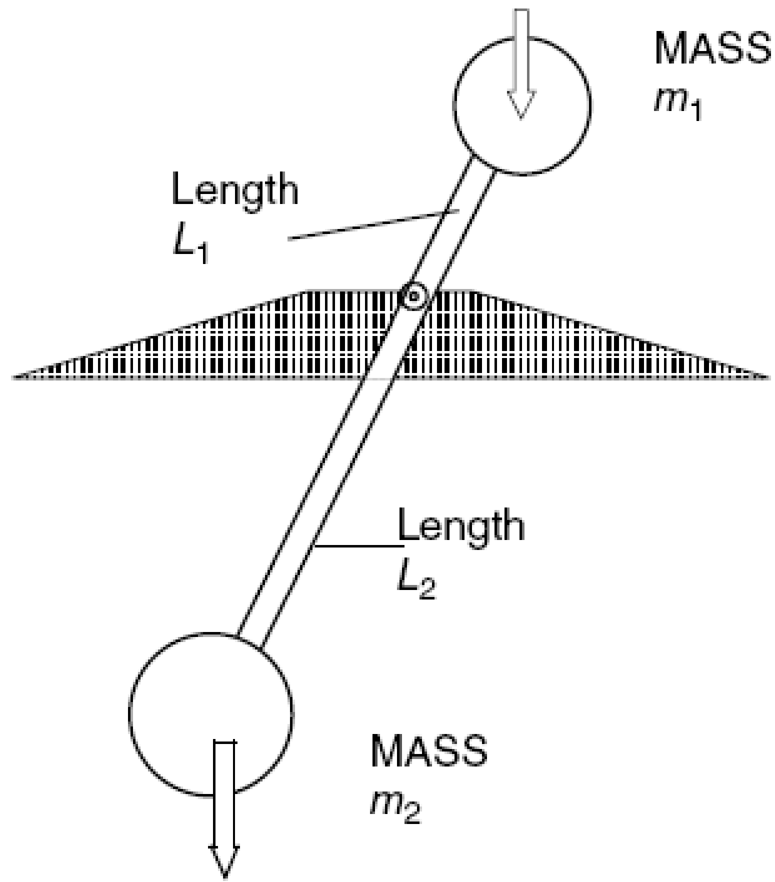
Basic Equations of Dynamics of Rigid Bodies

- Base on the rigid bodies like robot manipulator arm, or magnetically levitated vehicle or flexible structures in an MEMS accelerometer, the following equations much be used to correlate, namely:
  - Newton-Euler Equation (vector method)
  - Langrange's Equations (scalar-energy method)
  - D' Alembert's Principle (virtual work method)
  - Virtual Power Principle (Kane's Equation or Jordan Principles)

Magnetically levitated rigid body (HSST MagLev prototype vehicle, 1998, Nagoya, Japan).

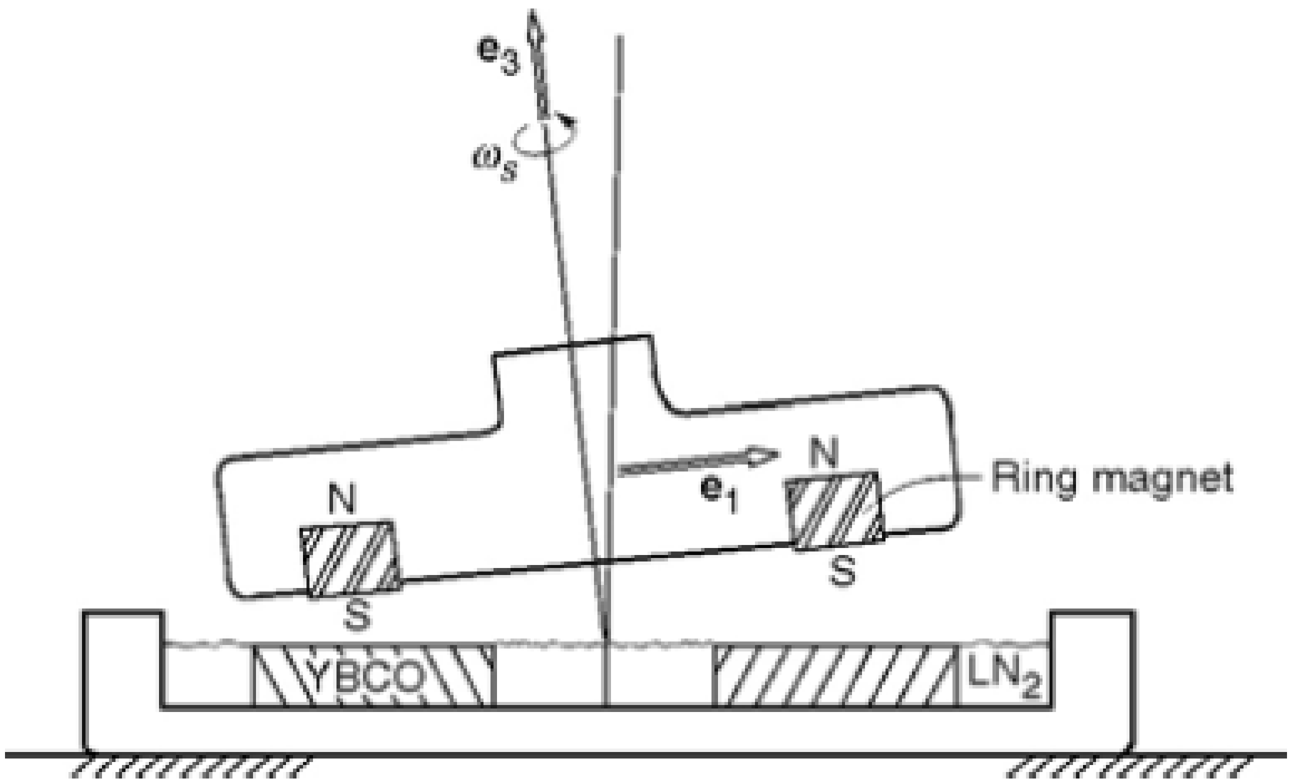
Simple Dynamic Models

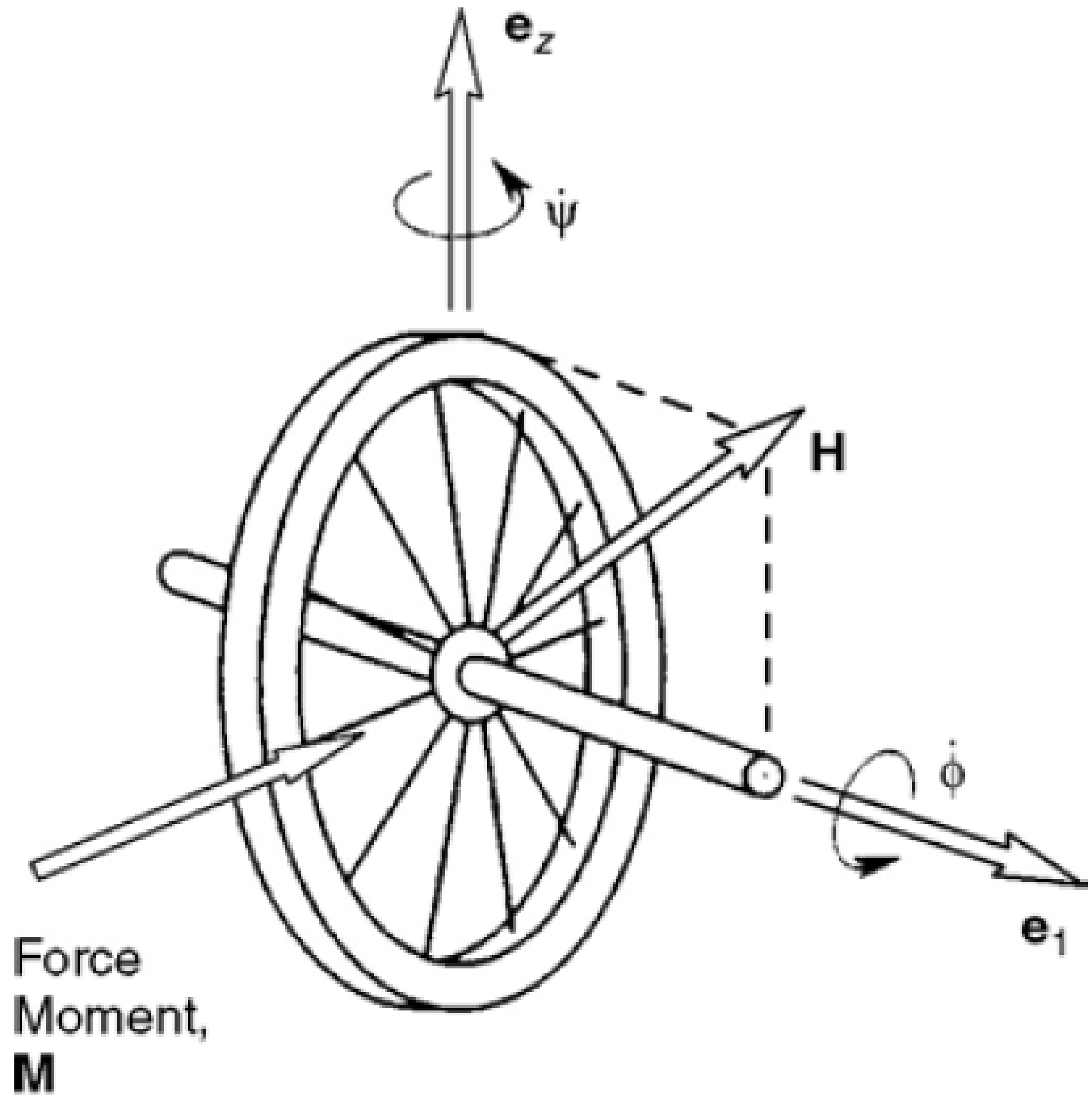
- Compound Pendulum



Simple Dynamic Models

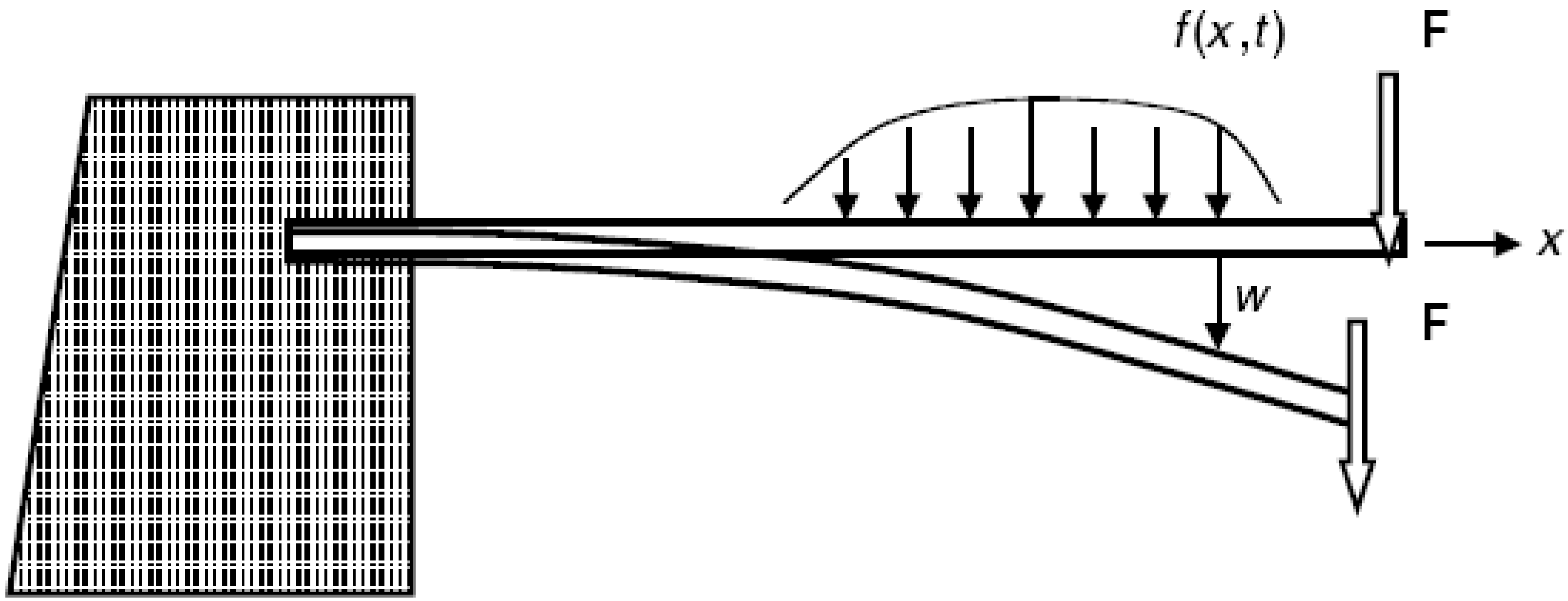
- Gyroscopic Motions





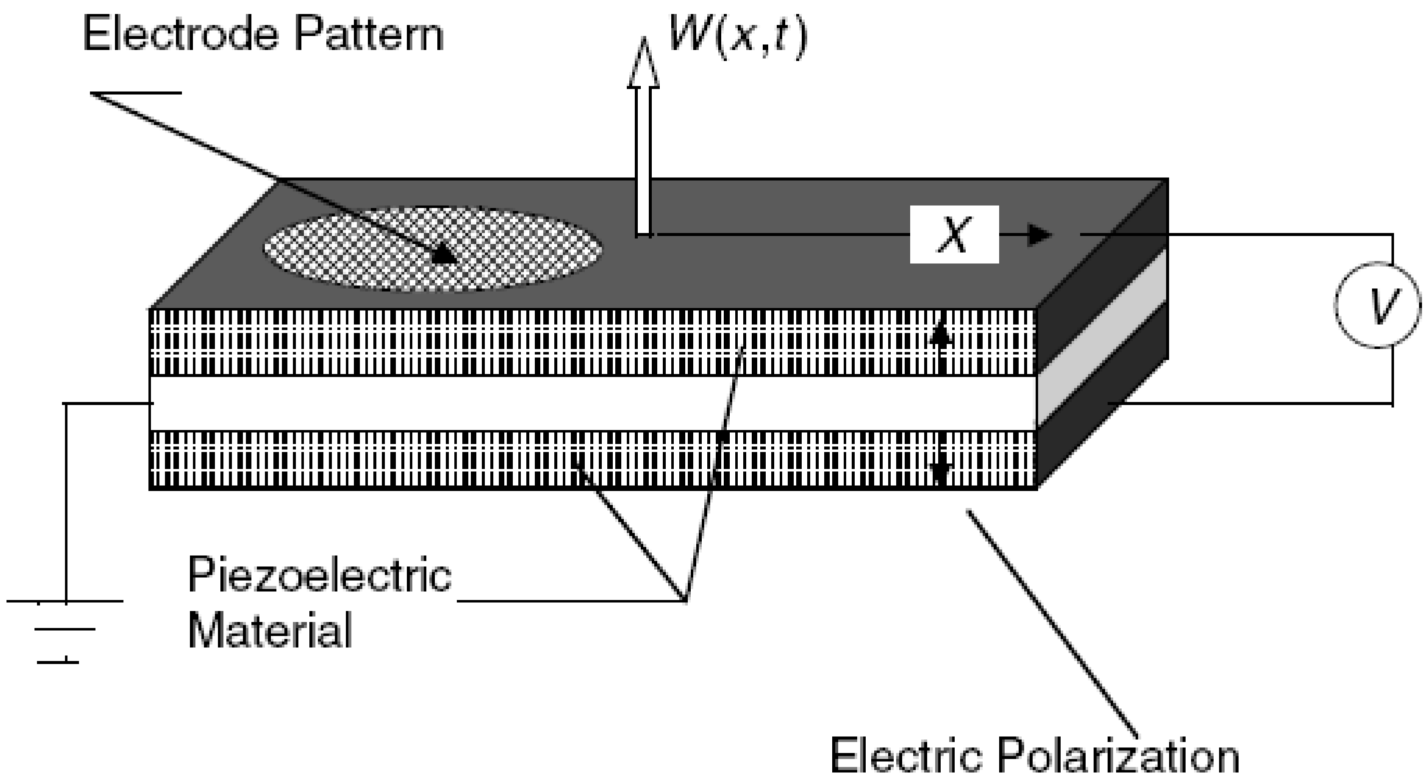
Gyroscopic moment on a precessing, spinning rigid body.

Elastic System Modeling



Sketch of an elastic cantilevered beam.

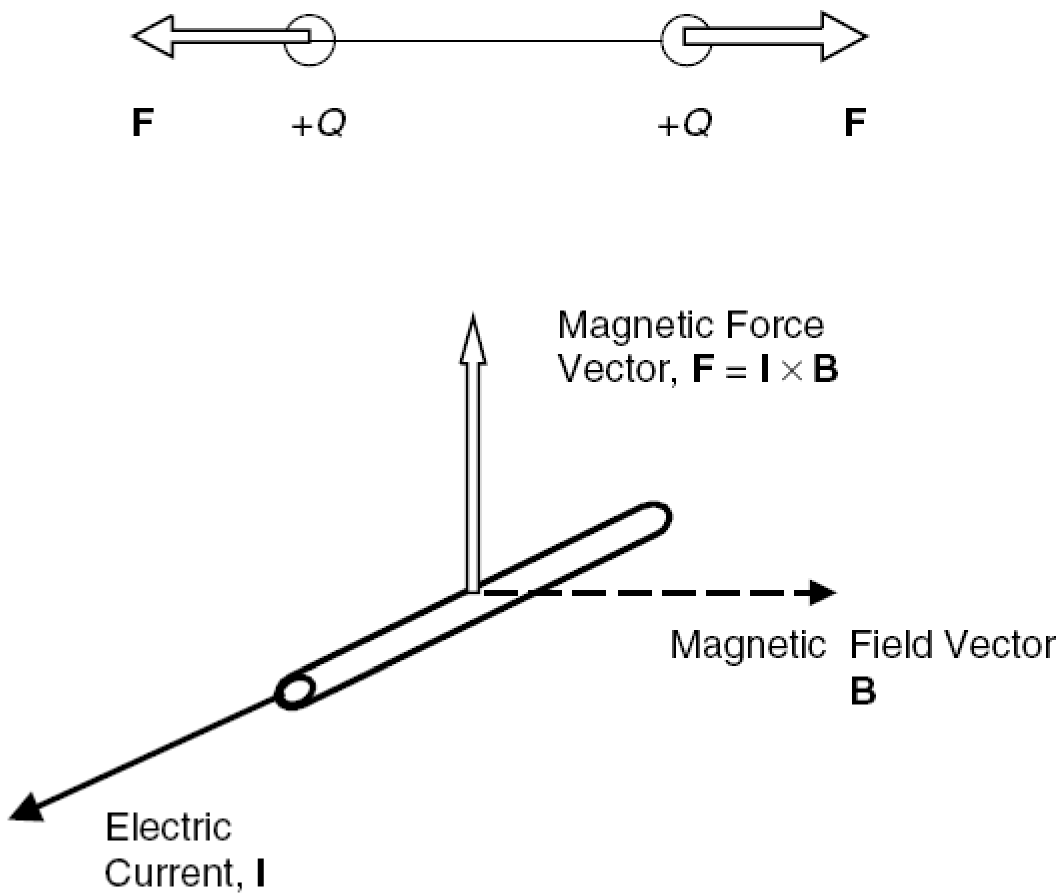
Elastic System Modeling



Elastic beam with two piezoelectric layers (Lee and Moon, 1989).

Electromagnetic Forces

- Electric forces at on charges and electric polarization (electric dipole).
- Magnetic forces act on electric currents and magnetic polarization.

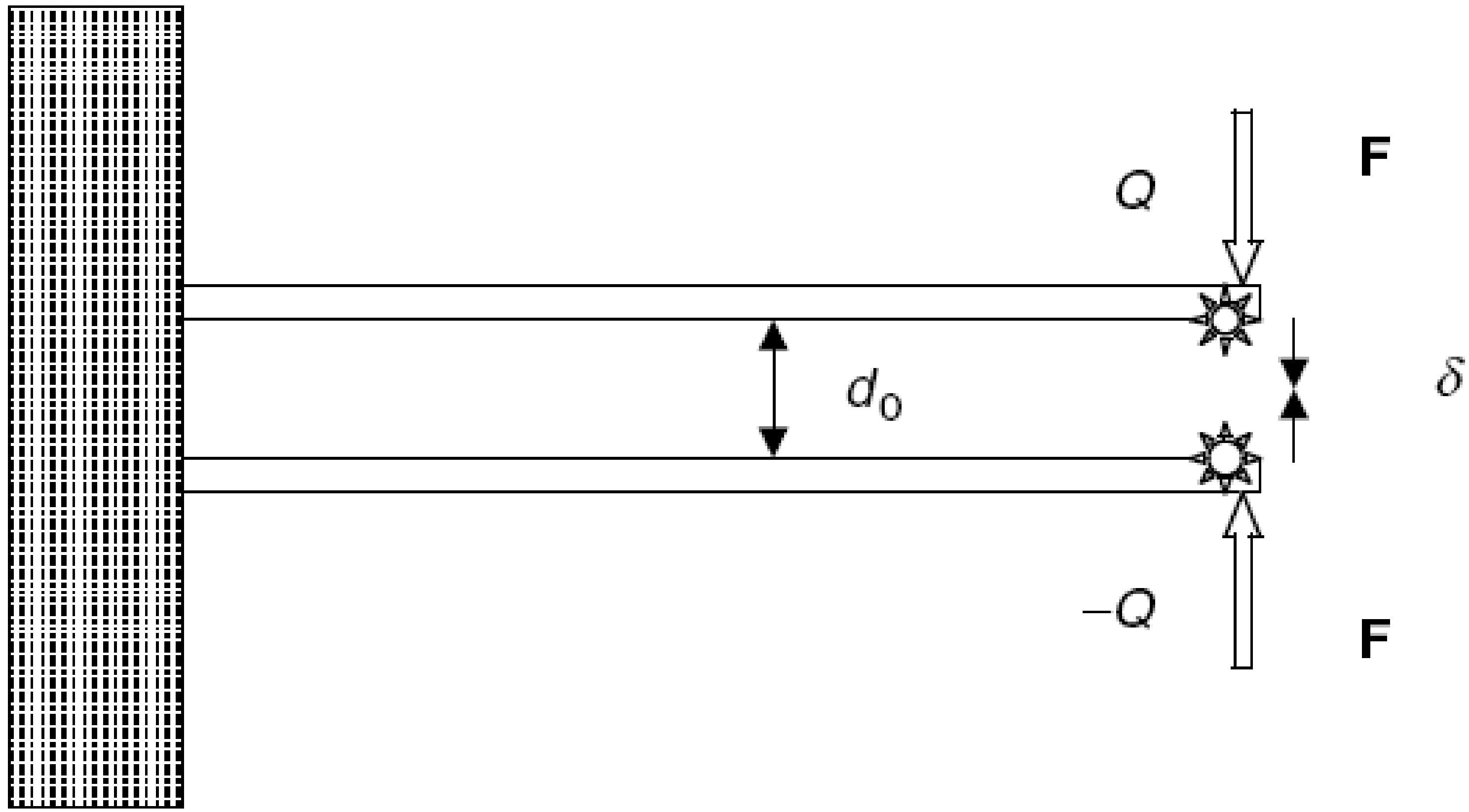


Electric forces on two charges (top). Magnetic force on a current carrying wire element (bottom).

Electromagnetic Forces

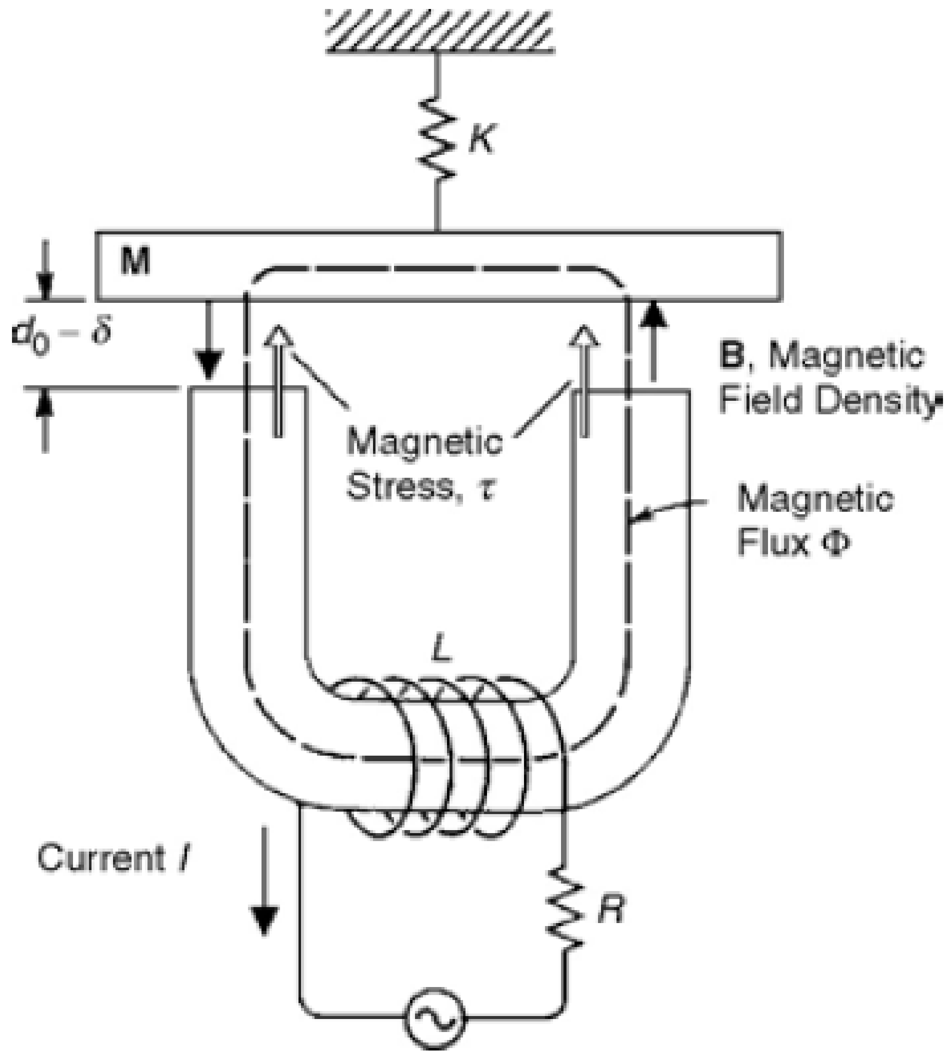
- Four principal methods to calculate electric and magnetic forces”
  1. Direct force vectors and moments between electric charges, currents, and dipoles;
  2. Electric field-charge and magnetic field-current force vectors;
  3. Electromagnetic tensor; integration of electric tension, magnetic pressure over the surface of a material body; and
  4. Energy methods based on gradients of magnetic and electric energy.

Example: Electromagnetic Forces



Two elastic beams with electric charges at the ends.

Example: Electromagnetic Forces

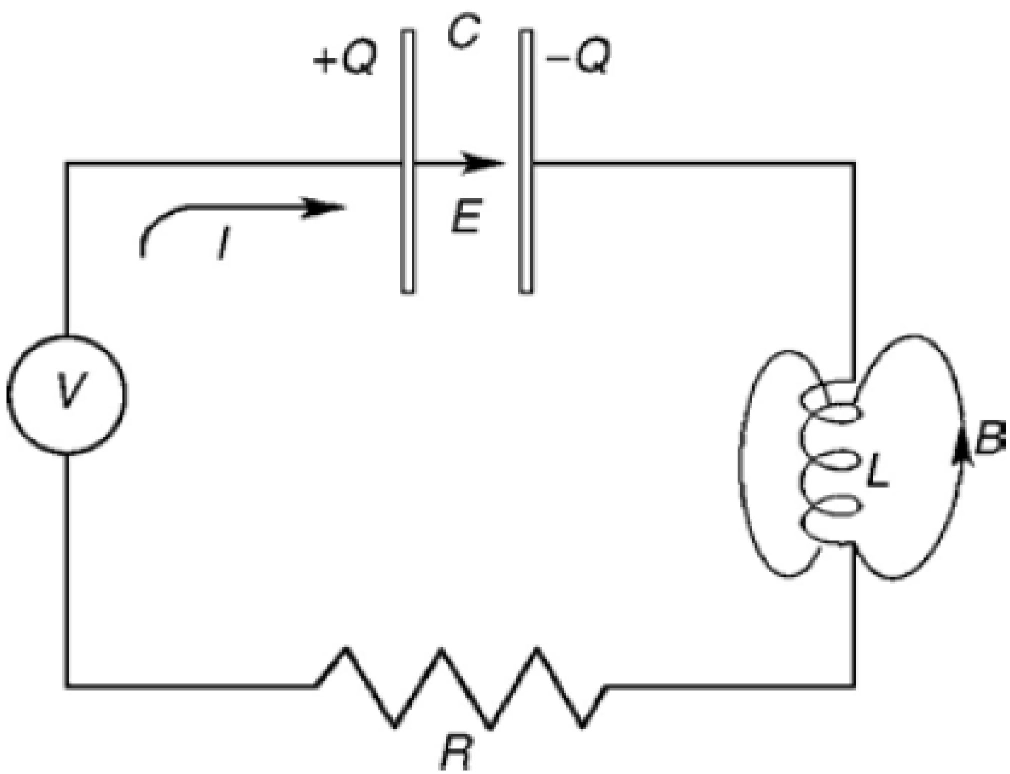


Force on a ferromagnetic bar near an electromagnet.

Dynamic Principles for Electric and Magnetic Circuits

$$V_{21} = \int_1^2 \mathbf{E} \cdot dl$$

$$\Phi = \int \mathbf{B} \cdot d\mathbf{A}$$



Electric circuit with lumped parameter capacitance, inductance, and resistance.

Dynamic Principles for Electric and Magnetic Circuits

$$\frac{dQ}{dt} = I \quad \text{(Conservation of charge)}$$

$$\frac{d\phi}{dt} = V \quad \text{(Law of flux change)}$$

$\phi = N\Phi$ is called the number of flux linkages, and N is an integer.

$$\phi = f(I)$$

In charge storage circuit elements, the capacitance C is defined as

$$Q = CV$$

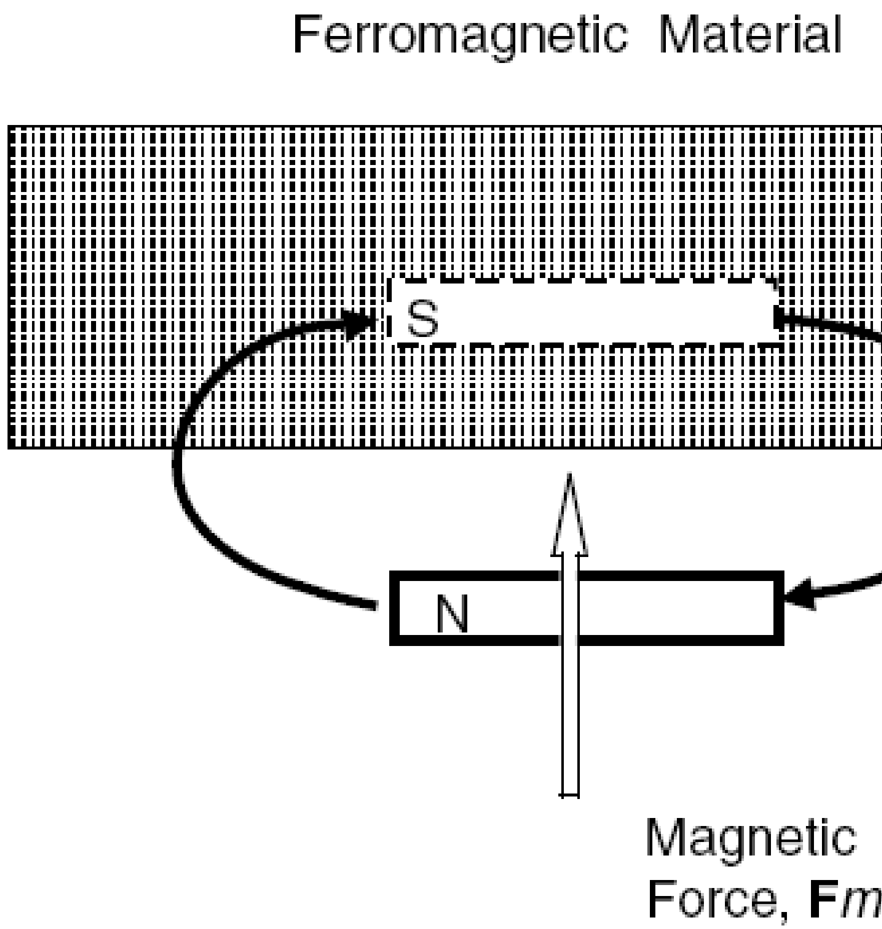
Kirchhoff circuit law:

$$\frac{d}{dt}L(x)I + \frac{Q}{C(x)} + RI = V(t)$$

Earnshaw’s Theorem and Electromechanical Stability

- It is not well known that electric and magnetic forces in mechanical systems can produce static instability, otherwise known as elastic buckling or divergence.
- This is a consequence of the inverse square nature of many electric and magnetic forces.
- It is well known that the electric and magnetic field potential Φ satisfies Laplace’s equation, inv of $\Delta^2 \Phi = 0$.

Earnshaw's Theorem and Electromechanical Stability



Example of electric force on the elements of a comb-drive actuator.