Sensors and Actuators

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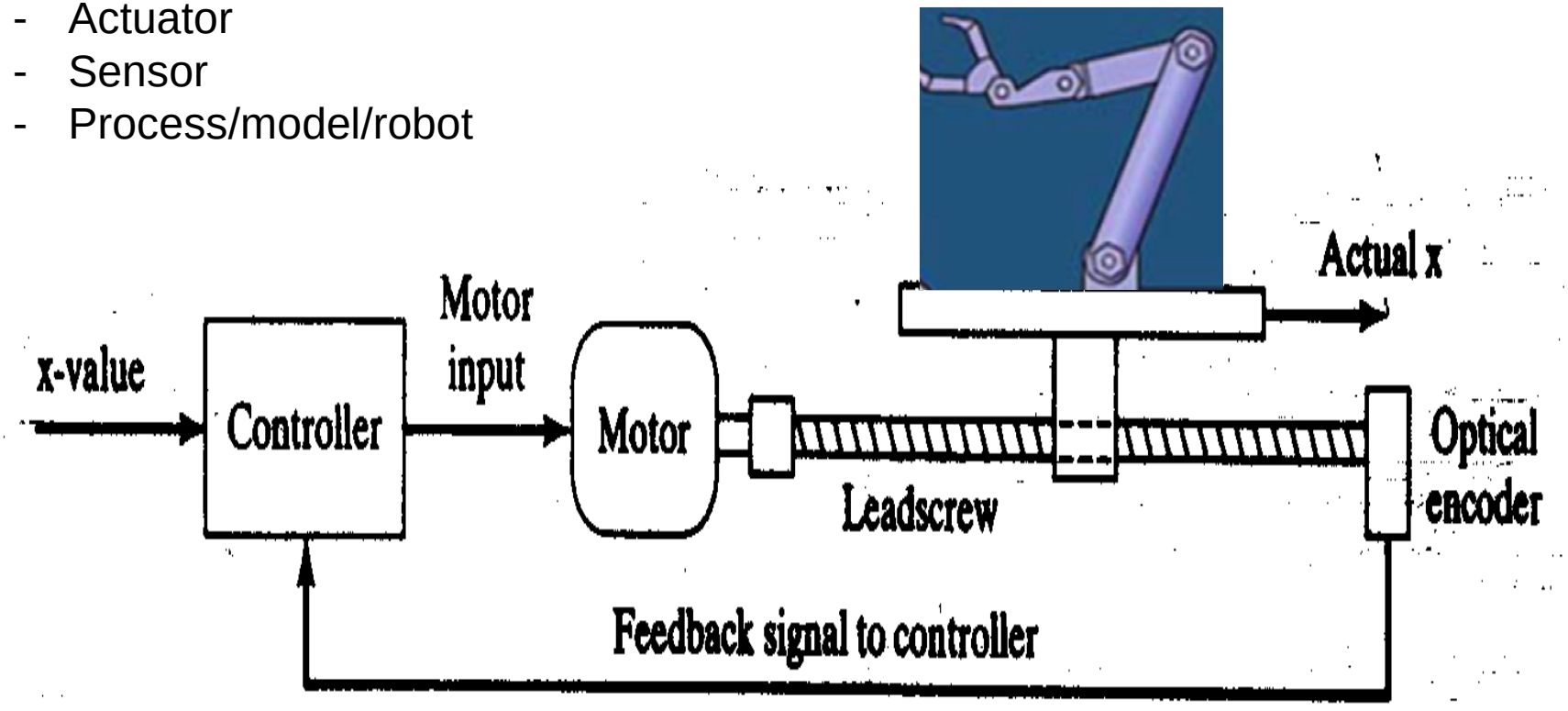
Sub-systems in control

- Controller
- Actuator
- Sensor
- Process/model/robot



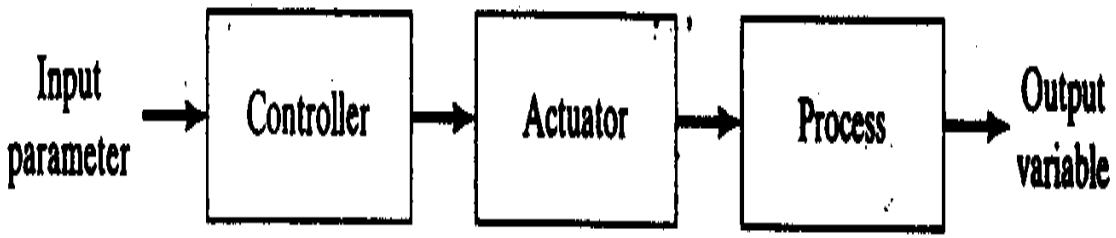
SIZE EFFECT ?

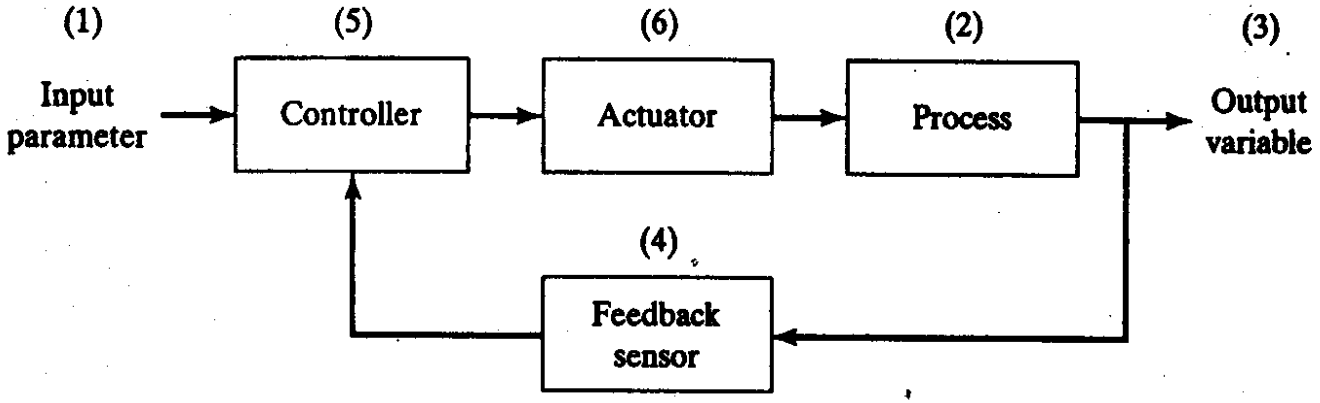
Basic elements

- Sensors
- Actuators
- Controllers
- System model

- **Basic definition of sensors and actuators** : energy conversion from one form to another !

Open loop and closed loop





General Classification of Sensors

- **Internal sensors:** required for basic working of the system (e.g. position, velocity,).

- **External sensors:** interaction with the environment (vision, force, …).

Sensors used for closed loop position control: Internal sensors

- Position
- Velocity
- Acceleration

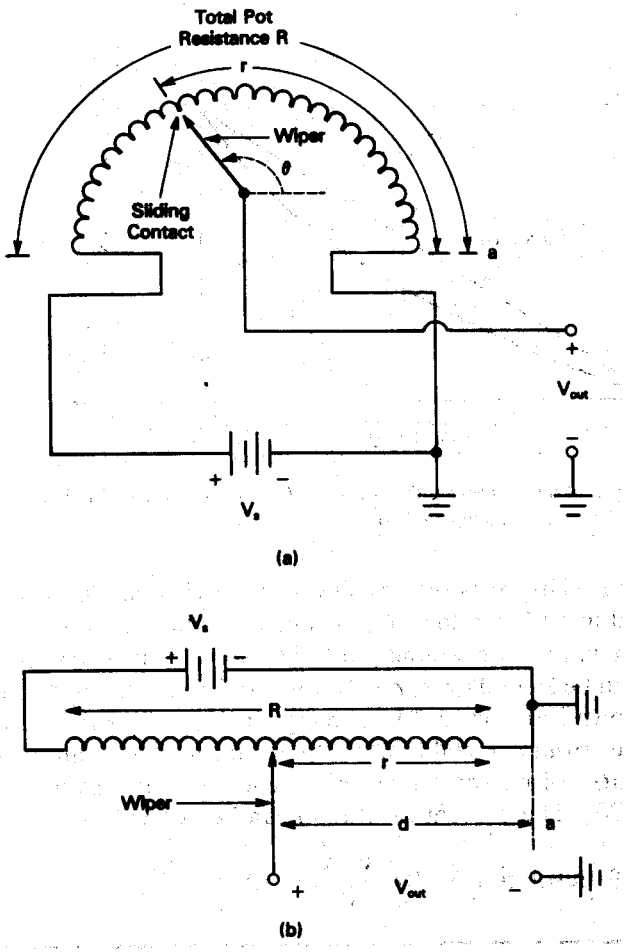
e.g. potentiometers, encoders, LVDT, Tachometers, Accelerometers

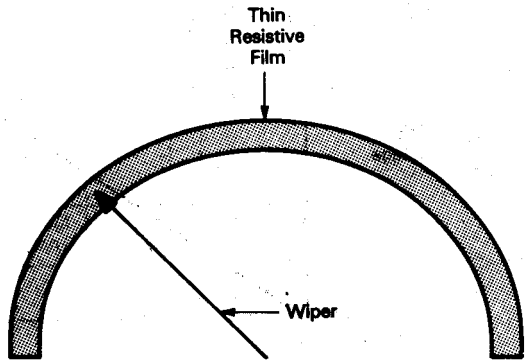
Sensors for interaction with the environment: External sensors

- **Touch**
- **Force**
- **Pressure**
- **Slip**
- **Proximity**
- **Vision**

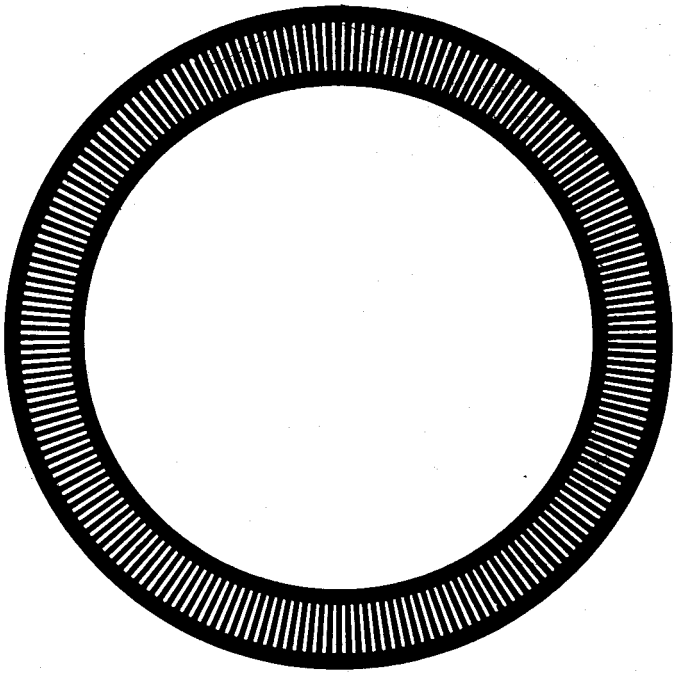
e.g. on/off switches, ultrasonic, force sensor, hall effect, inductive sensor, piezo sensor

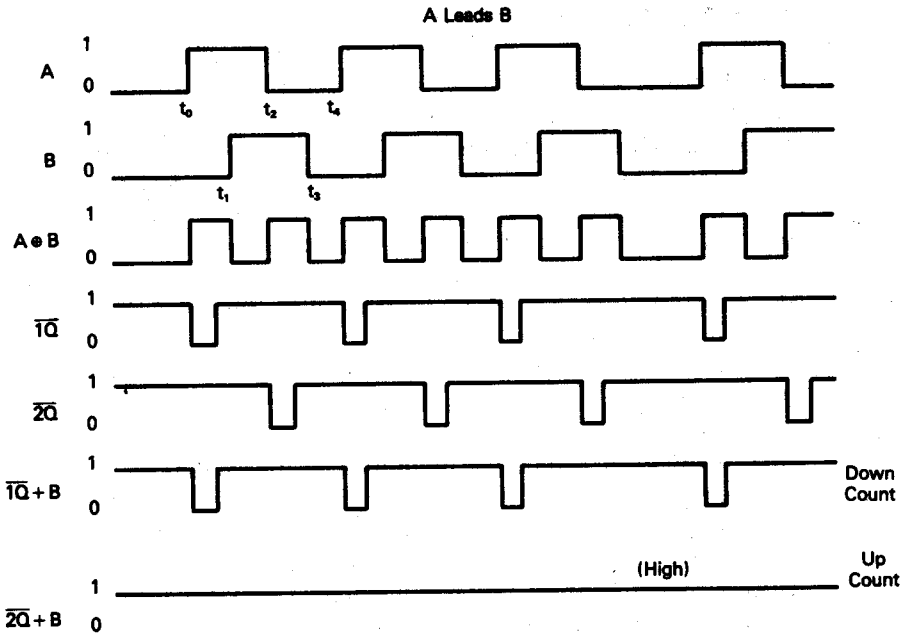
Position Sensor : Potentiometer





Position sensor: Incremental Encoder

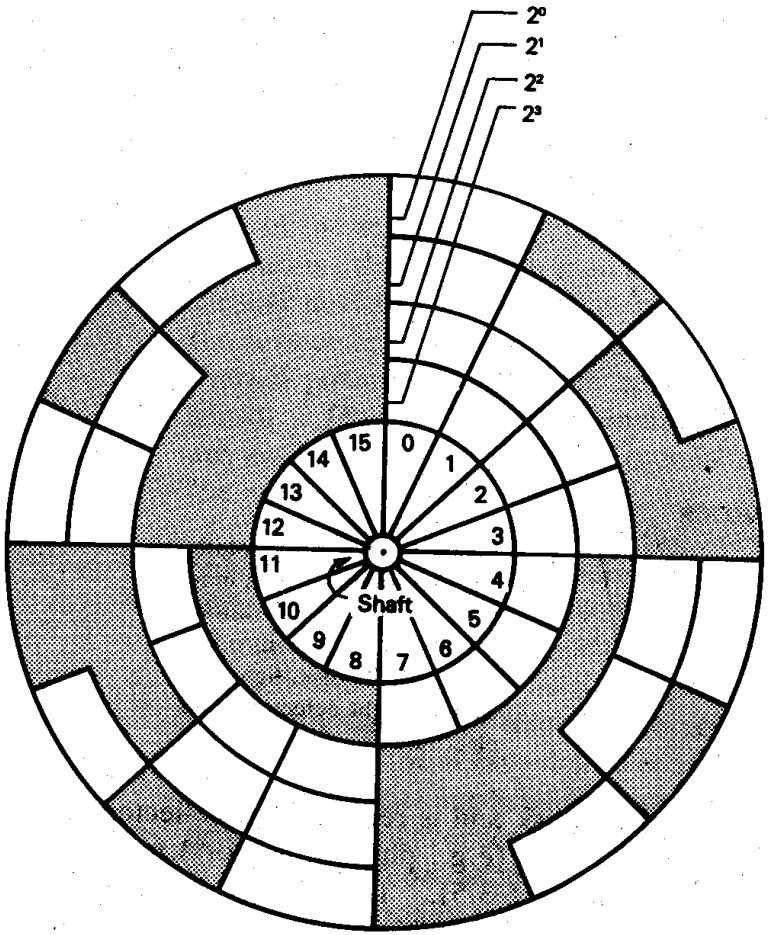




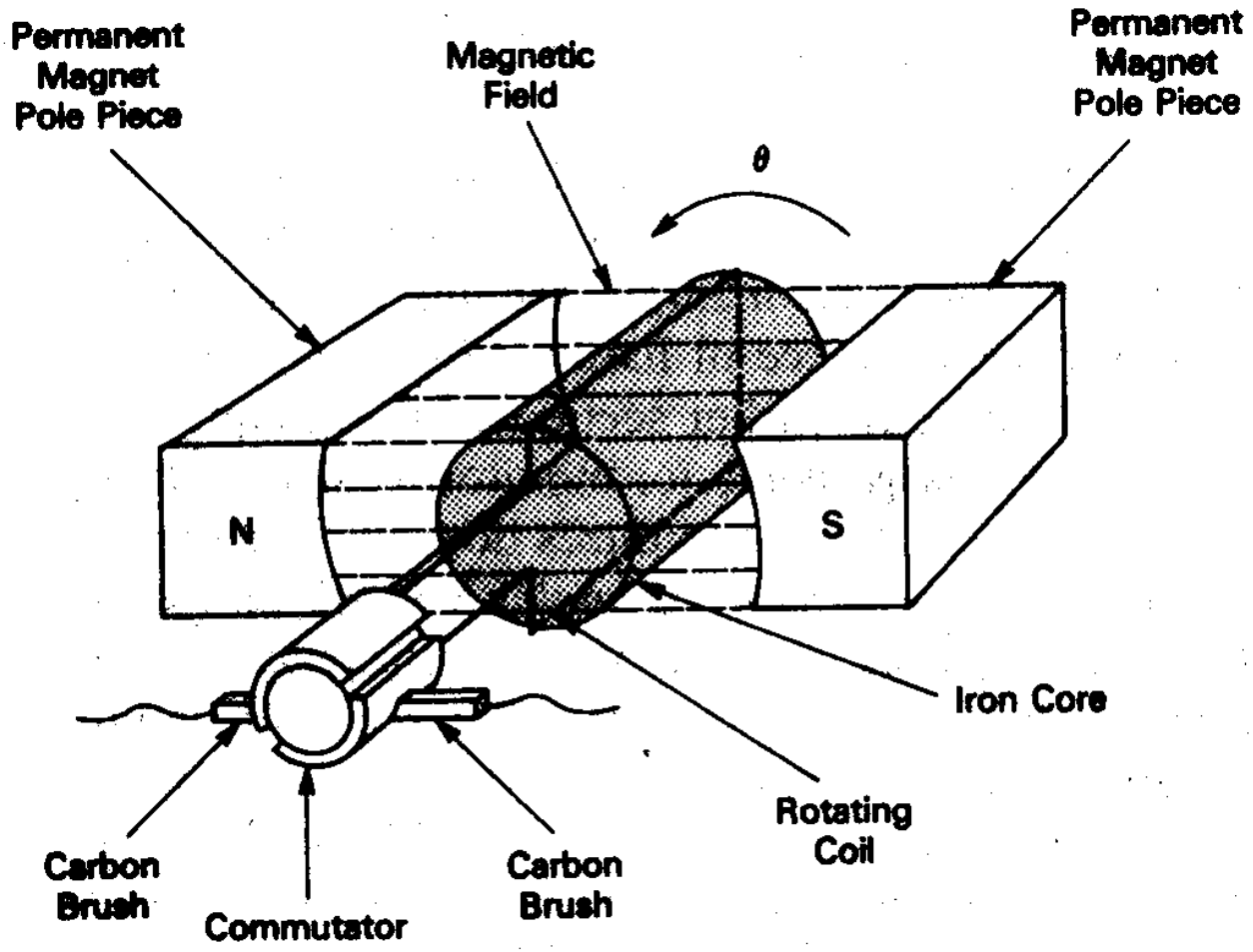
Using XOR gate

Position sensor : Absolute encoder

Grey code



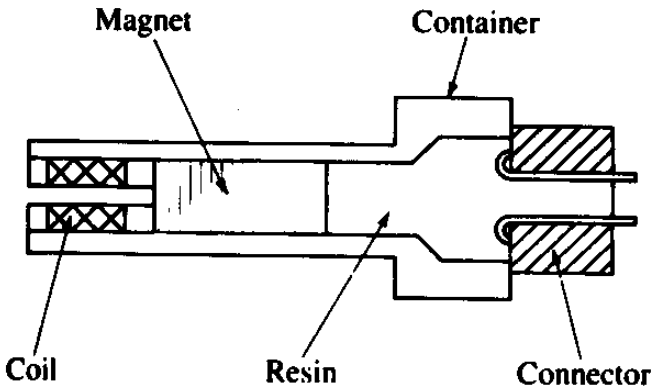
Velocity and acceleration sensors



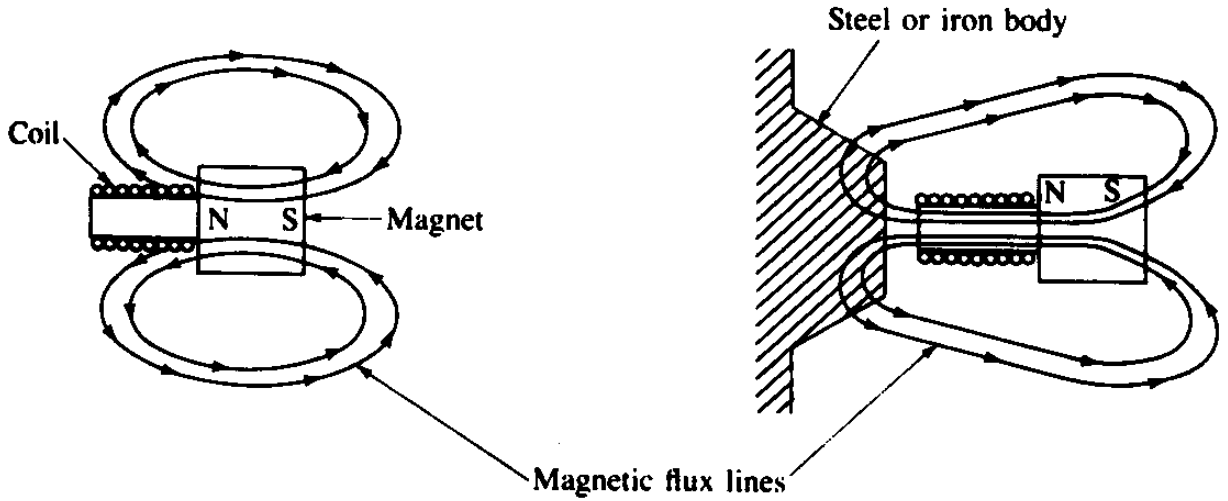
Touch sensors

- **On /Off switches**
- **Emitter / receiver pairs.**
- **Thermal / pressure sensors**

Proximity sensor : Inductive sensor

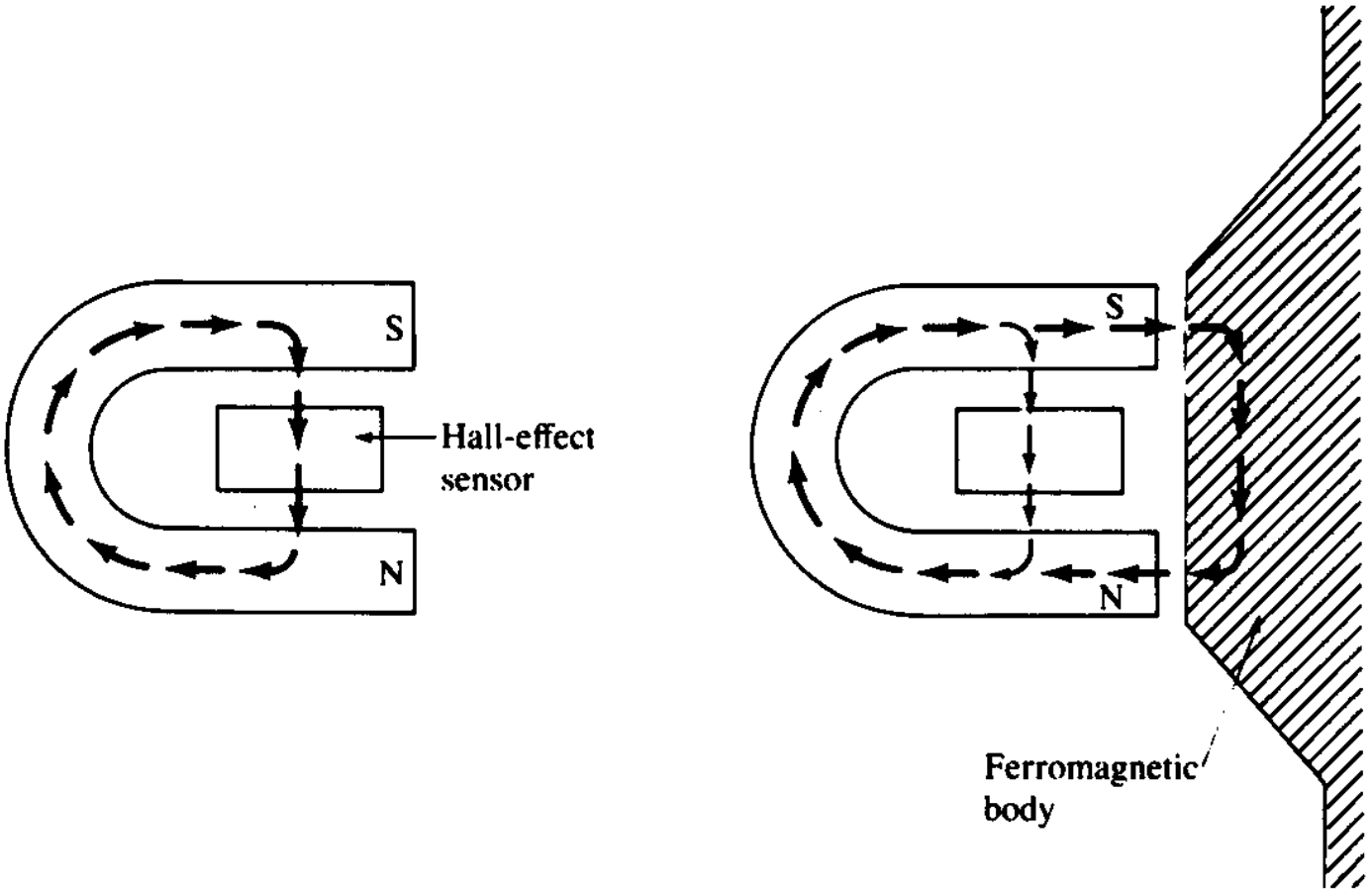


(*a*)

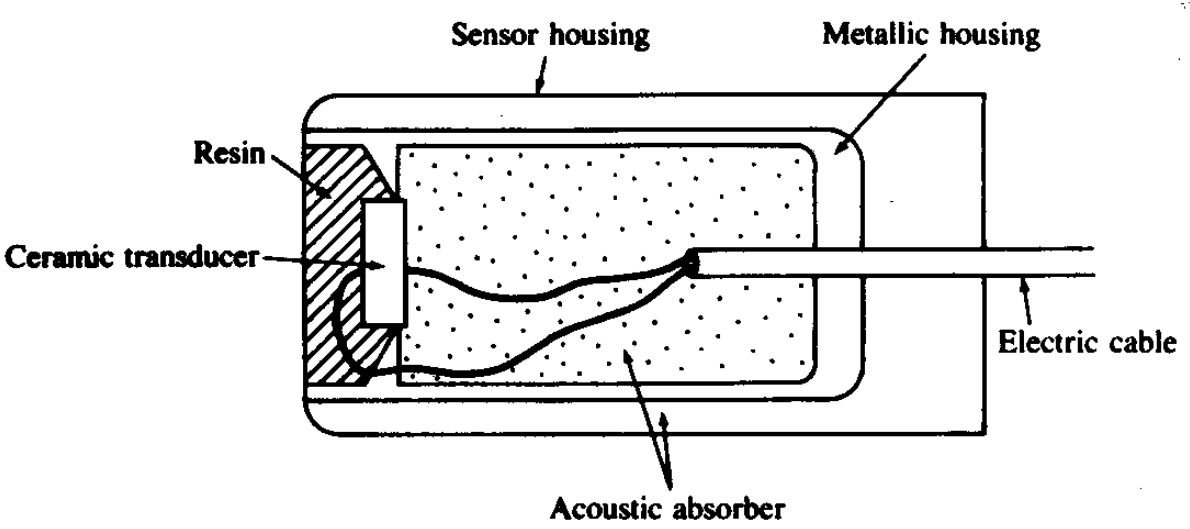


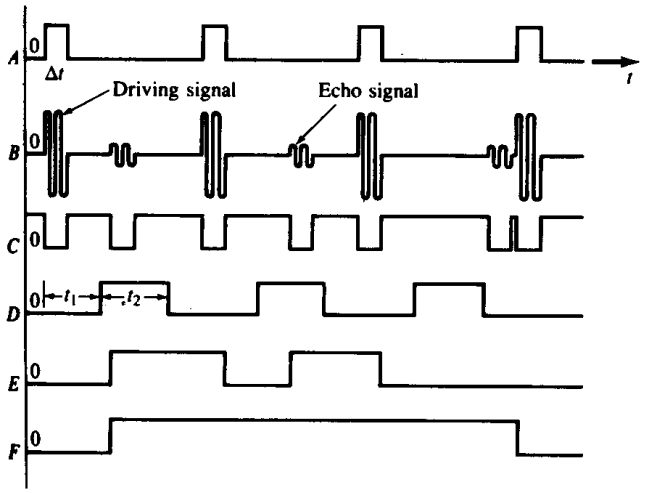
(*b*) (*c*)

Proximity sensor: Hall effect sensor

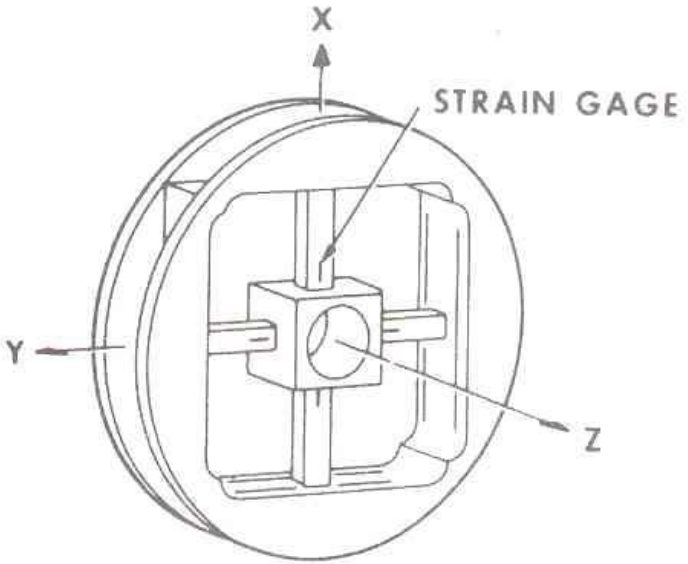


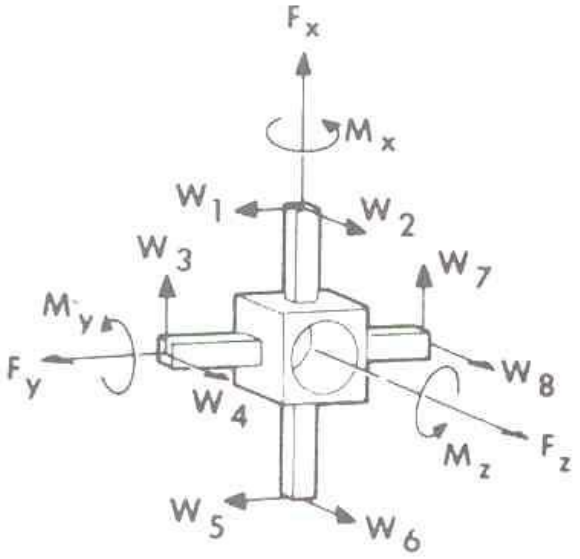
Range sensor : Ultrasonic sensor





Force sensors





TRANSFORMATION MATRIX UNDER IDEAL CONDITIONS

FORCES AND TORQUES REFERENCED TO X-Y-Z SENSOR COORDINATES

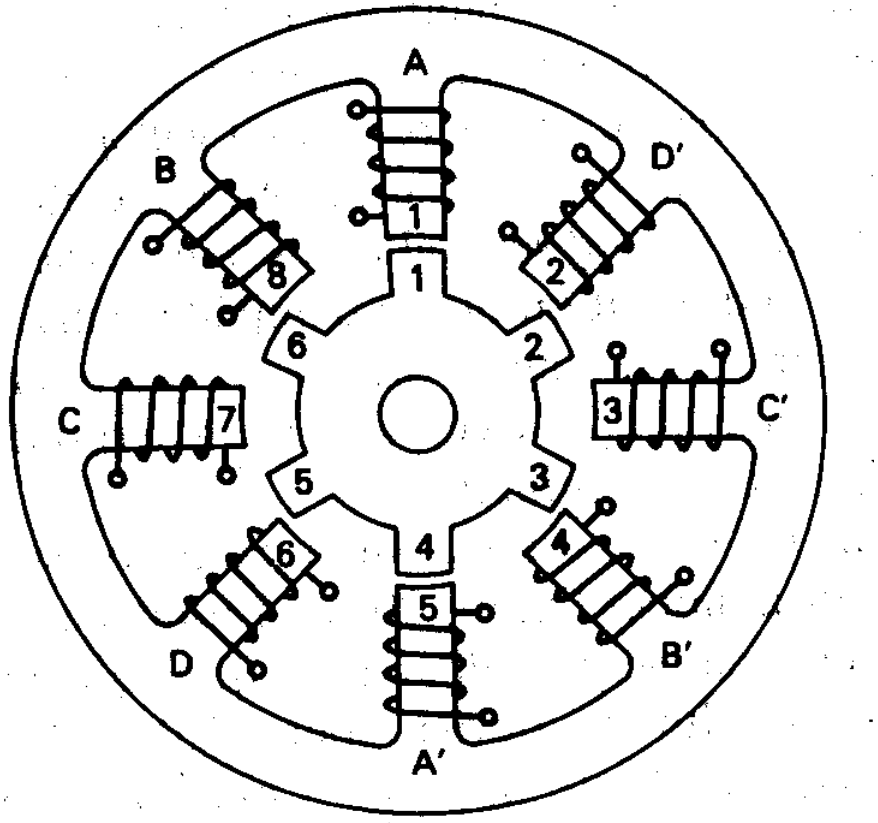
$$\begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & k_{13} & 0 & 0 & 0 & k_{17} & 0 \\ k_{21} & 0 & 0 & 0 & k_{25} & 0 & 0 & 0 \\ 0 & k_{32} & 0 & k_{34} & 0 & k_{36} & 0 & k_{38} \\ 0 & 0 & 0 & k_{44} & 0 & 0 & 0 & k_{48} \\ 0 & k_{52} & 0 & 0 & 0 & k_{56} & 0 & 0 \\ k_{61} & 0 & k_{63} & 0 & k_{65} & 0 & k_{67} & 0 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \\ W_5 \\ W_6 \\ W_7 \\ W_8 \end{bmatrix}$$

FORCES SENSED AT SPOKE ELEMENTS

Actuators

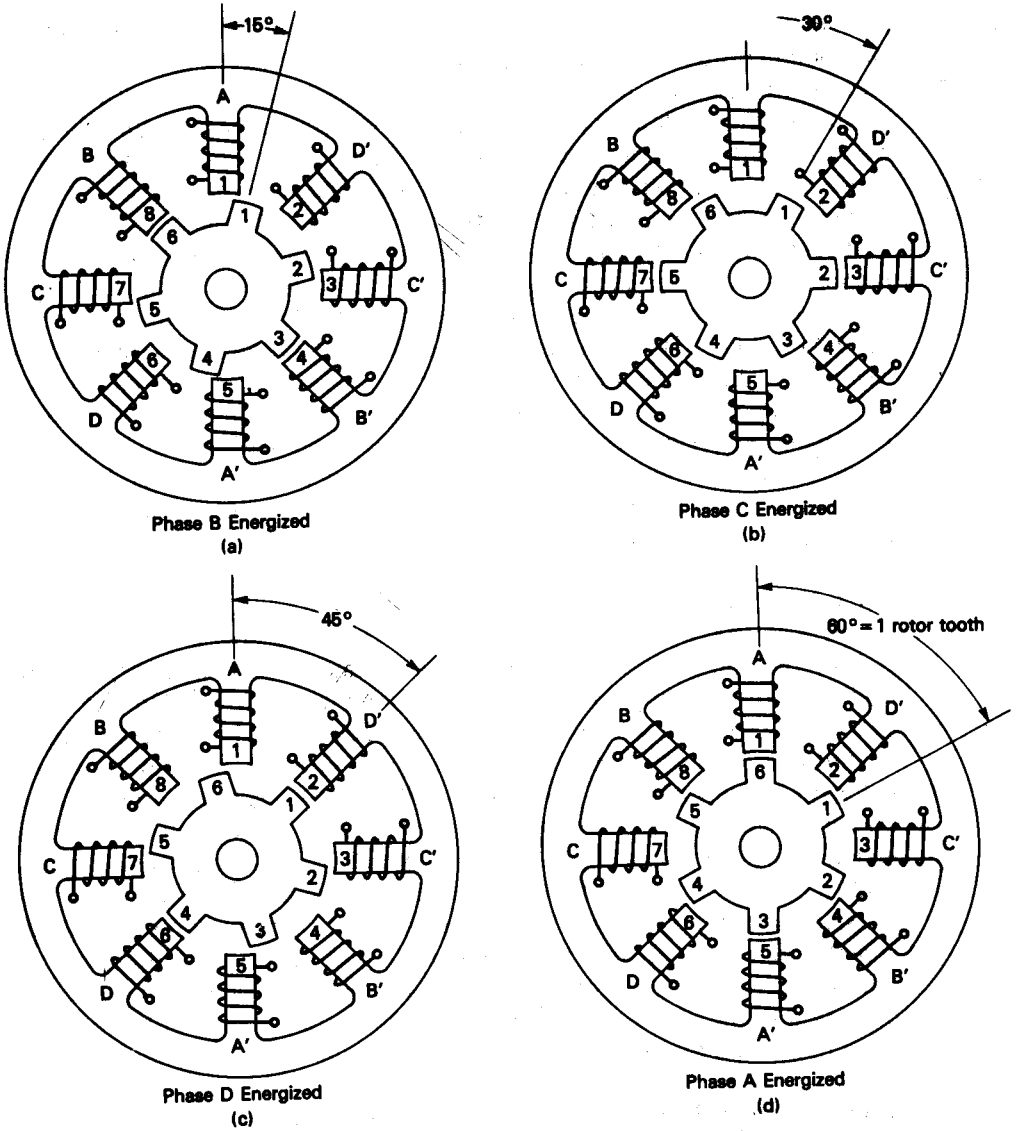
- ***Electrical*** **: stepper motors, DC servo motors**
- ***Pneumatic*** **: air pressure**
- ***Hydraulic*** **: fluid pressure (oil pressure).**
- ***Advanced actuators*** **: ultrasonic motors, artificial muscles, molecular motors.**

Stepper motors : Variable reluctance, permanent magnet

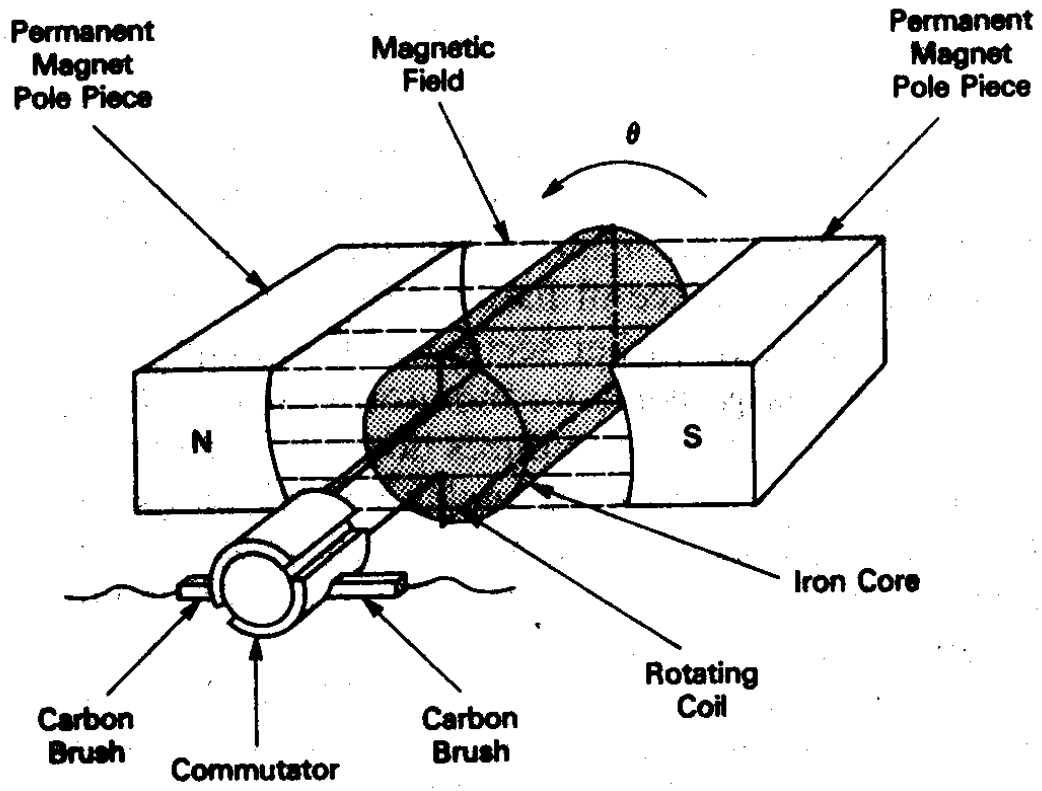


Working of a stepper motor

Sequence of rotation (CW): B – C – D - A’



DC Motors : basic working



Brushless DC motors

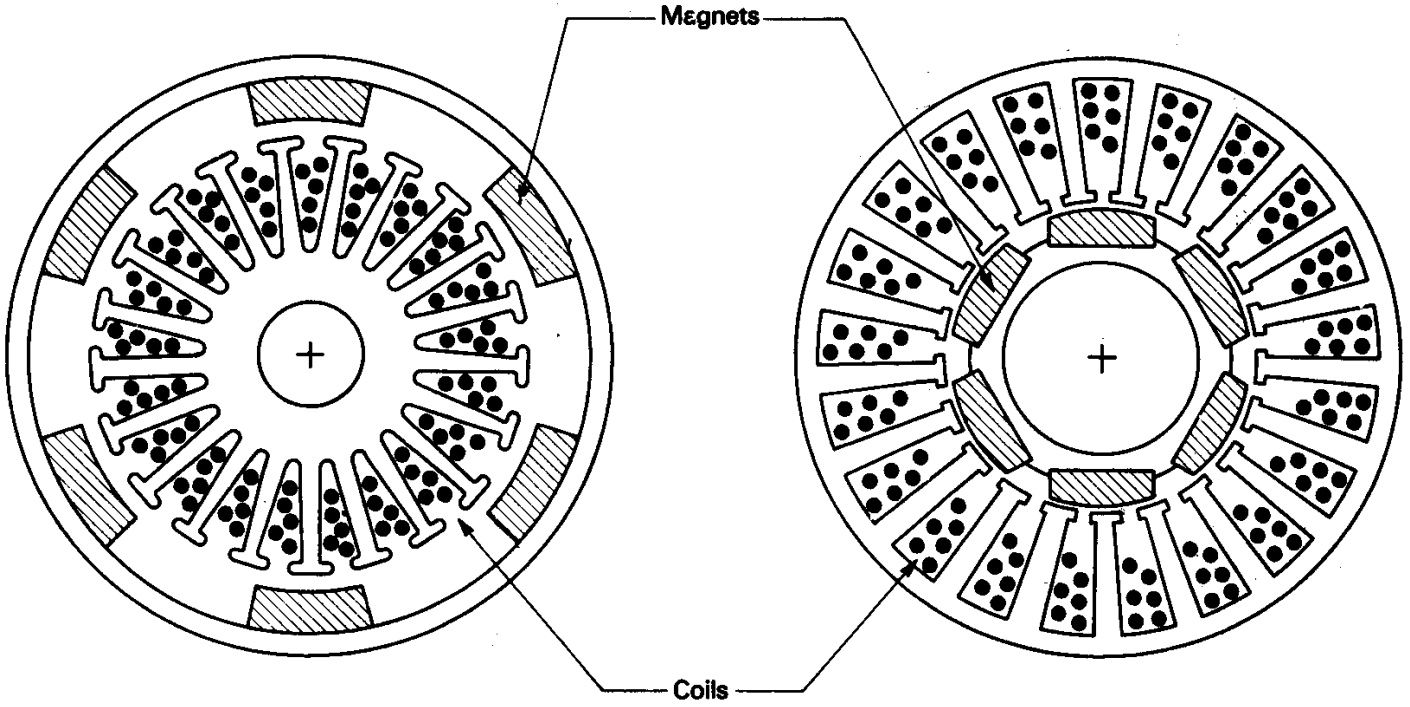
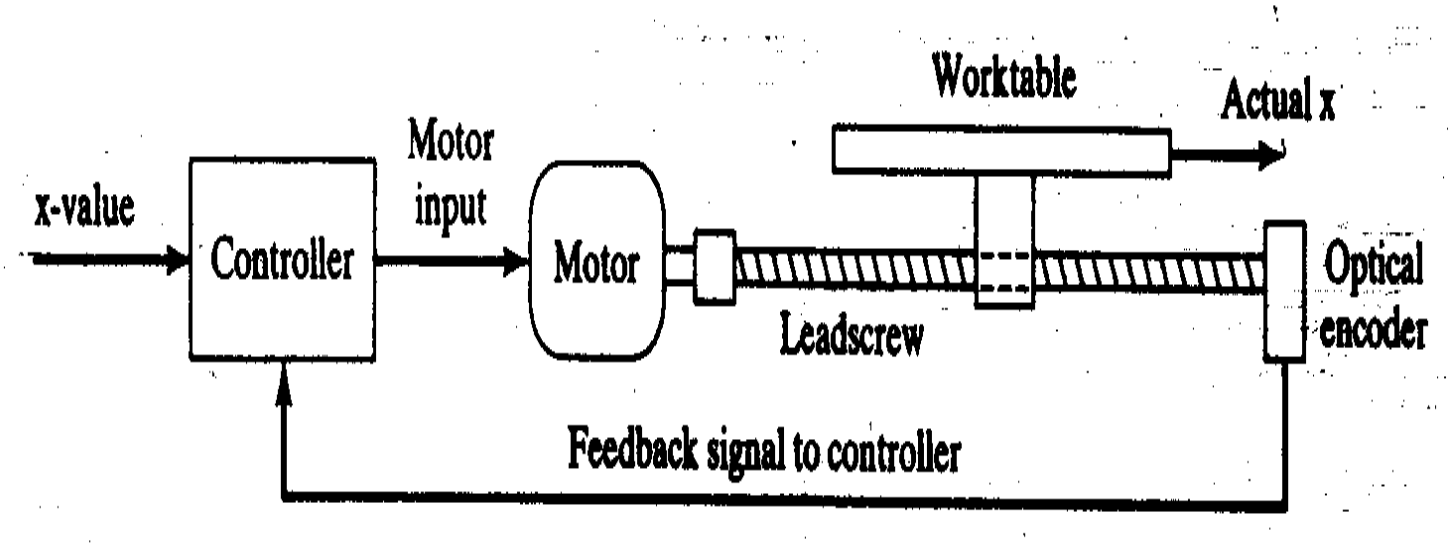


Fig. Brush type DC motor

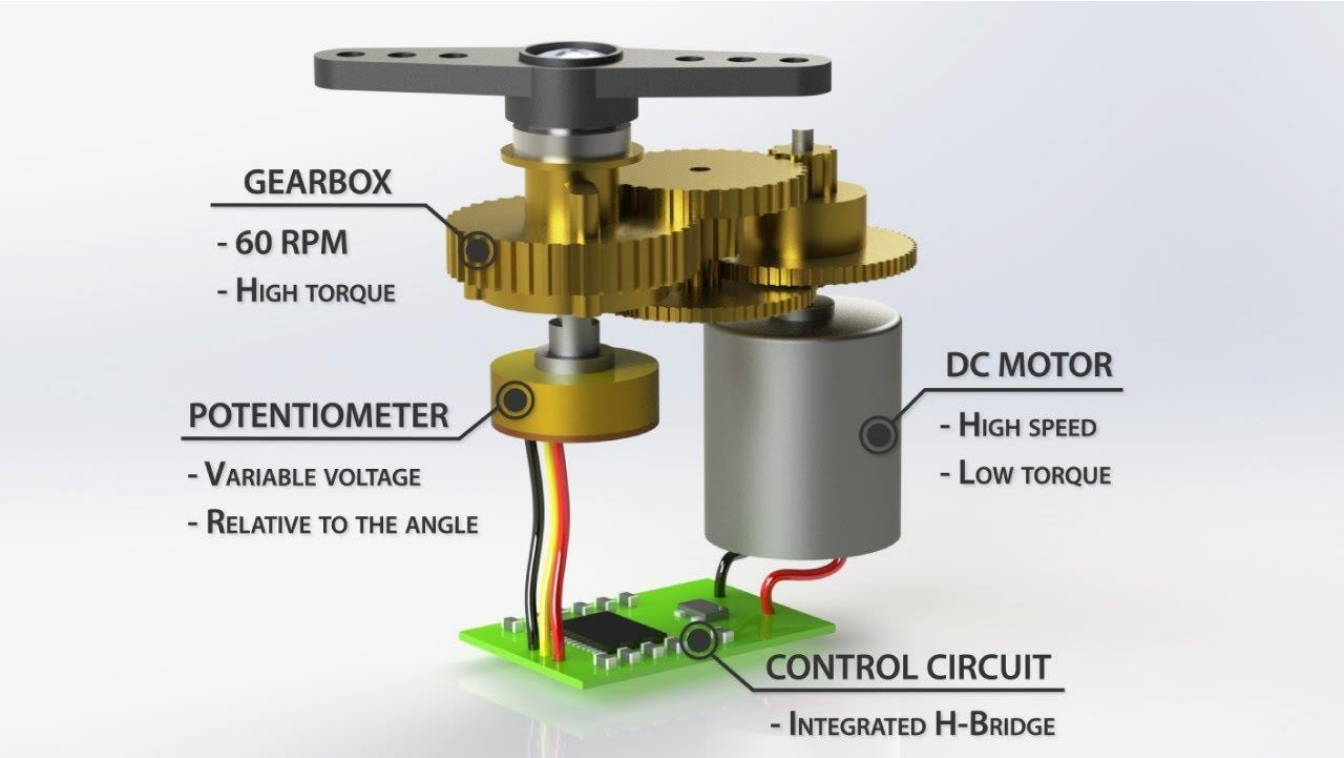
Fig. Brushless DC motor

DC servo motors

- DC motors working in closed loop position control.

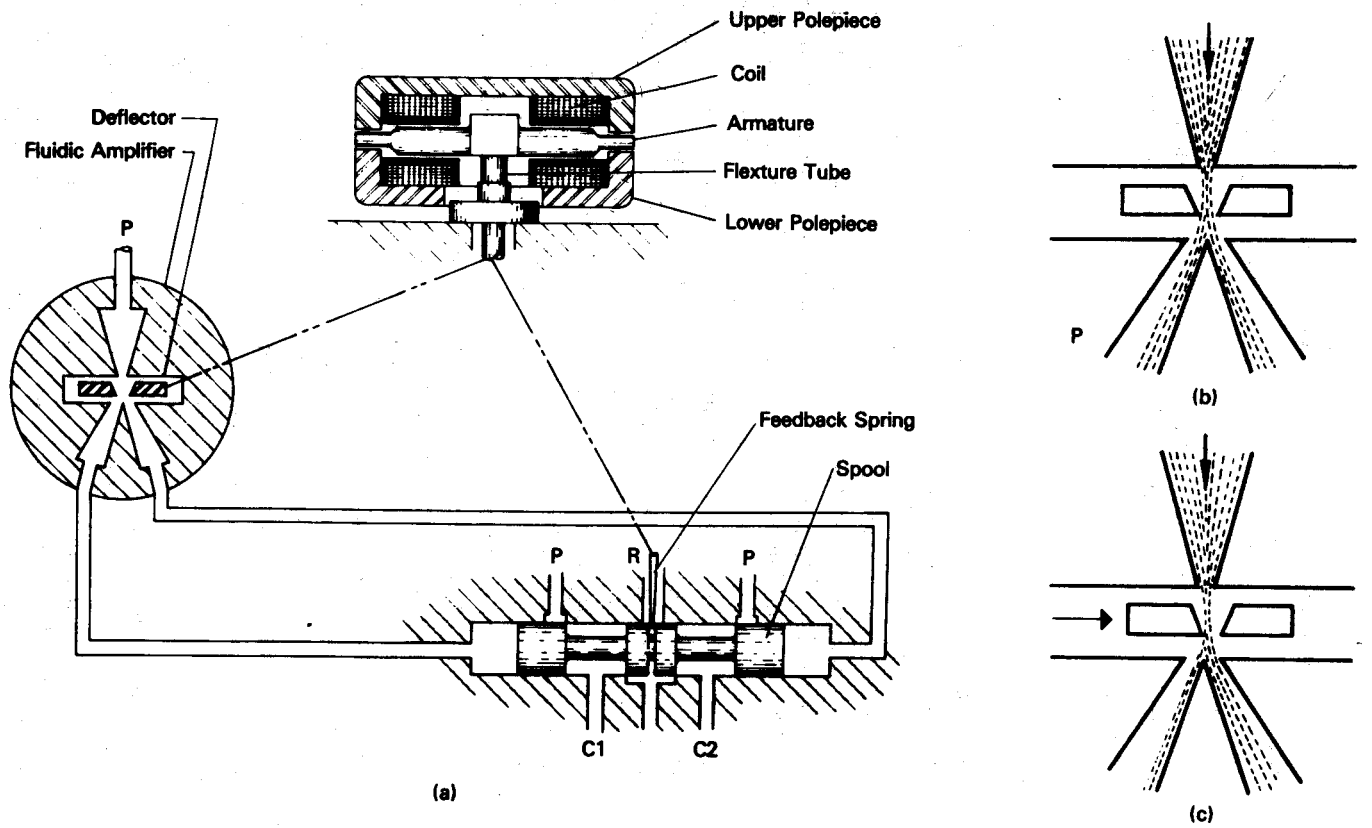


Servo


GEARBOX
- 60 RPM
- HIGH TORQUE
POTENTIOMETER
- VARIABLE VOLTAGE
- RELATIVE TO THE ANGLE
DC MOTOR
- HIGH SPEED
- LOW TORQUE
CONTROL CIRCUIT
- INTEGRATED H-BRIDGE

Servo motor

Pneumatic actuators



Advanced actuators: small, low power consumption, micro motion

- **Ultrasonic motors : micro robots, cameras, micro motion devices ..**
- **Artificial muscles : prosthetic, bio applications..**
- **Molecular motors : bio applications**

Ultrasonic motors

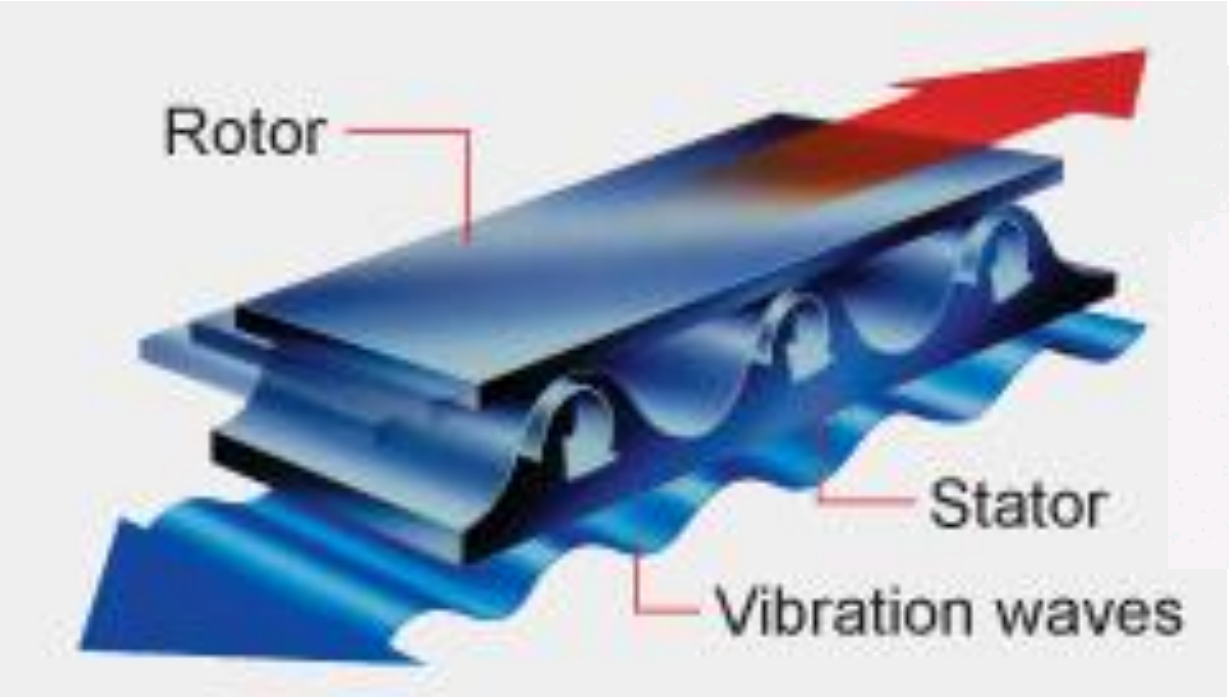


Fig. Motion due to dry friction and vibration.

Fig. Ring motors used in cameras.

Comparison of smart actuators

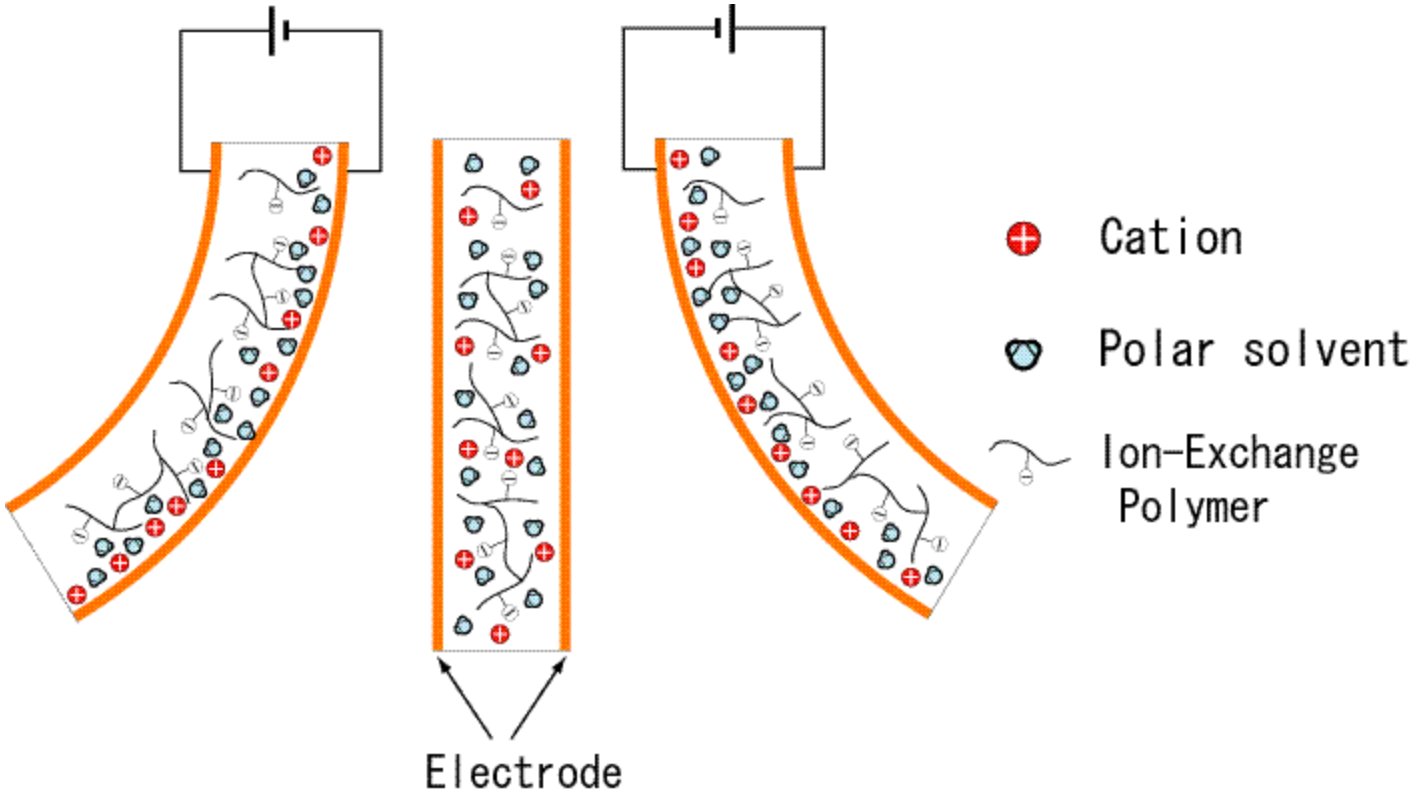
- **Piezo electric materials- large forces, small strains and fast response time.**
- **IPMCs- small forces, large straines, slower response times.**
- **(power) IPMC = (1/100) Natural Muscle.**

TABLE 1: Comparison of the properties of IPMC, SMA and EAC

Property	Ionic polymer-Metal Composites (IPMC)	Shape Memory Alloys (SMA)	Electroactive Ceramics (EAC)
Actuation displacement	>10%	<8% short fatigue life	0.1 - 0.3 %
Force (MPa)	10 - 30	about 700	30-40
Reaction speed	µsec to sec	sec to min	µsec to sec
Density	1- 2.5 g/cc	5 - 6 g/cc	6-8 g/cc
Drive voltage	4 - 7 V	NA	50 - 800 V
Power consumption	watts	watts	watts
Fracture toughness	resilient, elastic	elastic	fragile

Electro active Polymers

- Movement of ions and creations of micro channels.



IPMC motion

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