Actuators and Sensors

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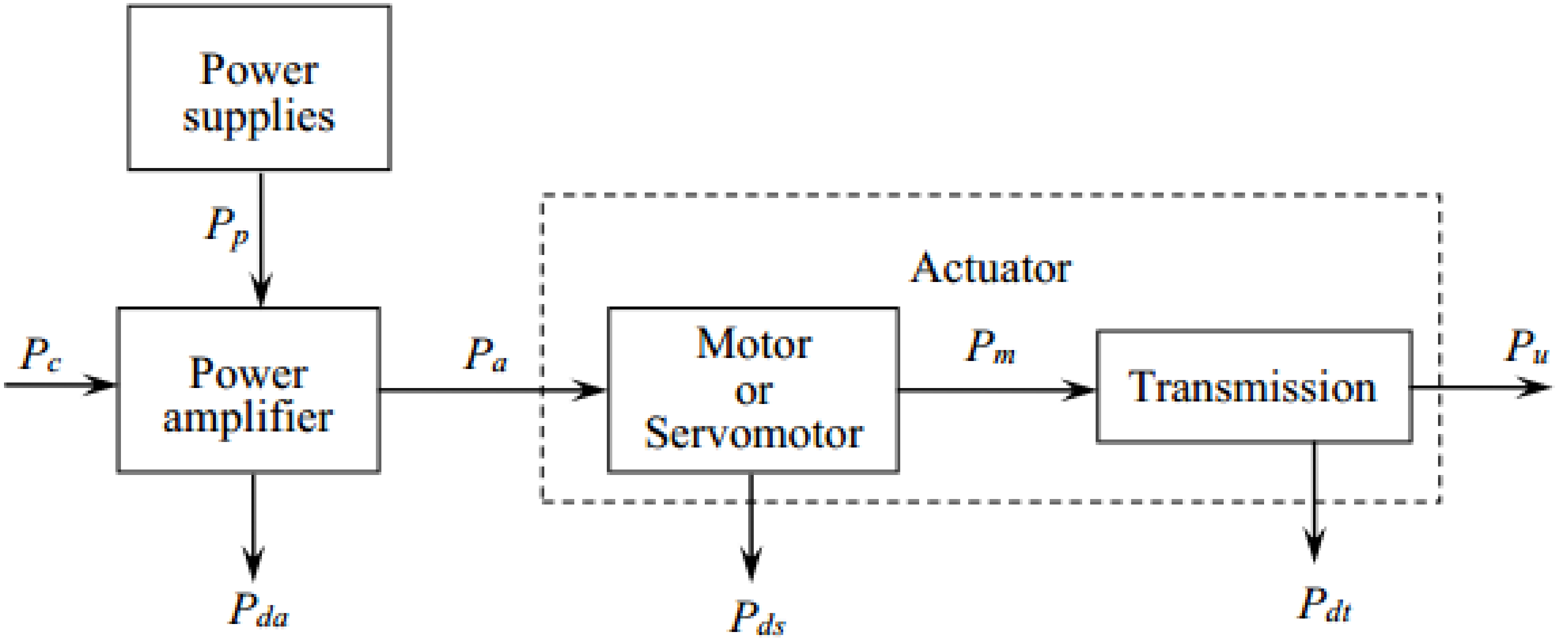
Outline

- Actuators
  - Electric
  - Hydraulic
  - Pneumatic
- Selection of motors
- Sensors
  - Internal
  - External

Actuation System



P_p: Primary source of power (electricity or pressurized fluid or compressed air); P_c: Input control power (usually electric); P_a: Input power to motor (electric or hydraulic or pneumatic type); P_m: Power output from motor; P_u : Mechanical power required; P_{da}, P_{ds}, and P_{dt}: Powers lost in dissipation for the conversions performed by the amplifier, motor, and transmission

Electric Actuators

- Electric motors

  +

- Mechanical transmissions
- First commercial electric motor: 1974 by ABB

Advantages vs. Disadvantages

- *Advantages*
  - Widespread availability of power supply.
  - Basic drive element is lighter than fluid power.
  - High power conversion efficiency.
  - No pollution
  - High accuracy + high repeatability compared to cost.
  - Quiet and clean

- Easily maintained and repaired.
- Components are lightweight.
- Drive system is suitable to electronic control.

- *Disadvantages*
  - Requires mechanical transmission system.
  - Adds mass and unwanted movement.
  - Requires additional power + cost.
  - Not safe in explosive atmospheres.

Stepper Motors

- Types
  - Variable Reluctance
  - Permanent Magnet
  - Hybrid
- Small/Medium end of industrial range
- Digitally controlled → No feedback
- Incremental shaft rotation for each pulse

Stepper Motor (Bipolar, 200 Steps/Rev, 20×30mm, 3.9V, 0.6 A/Phase)
[Courtesy: http://www.polulu.com]

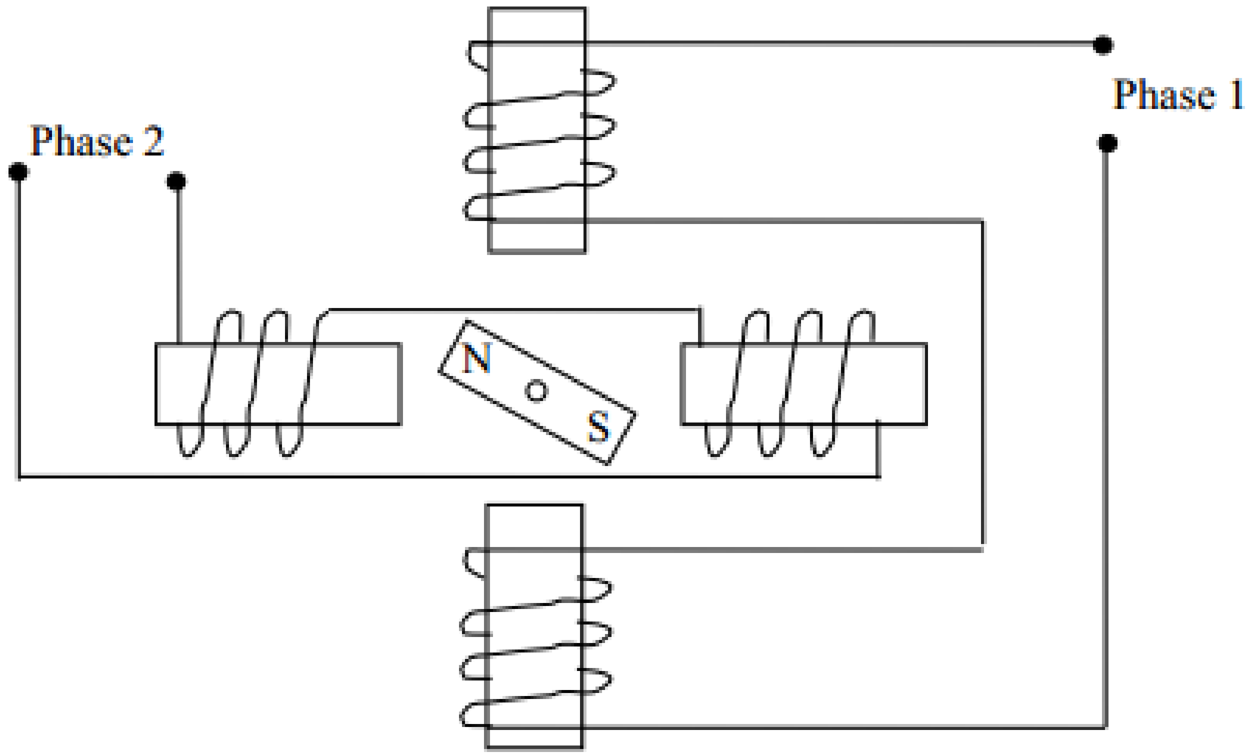


Fig. (a) A 2-phase stepper motor

- Steps range from 1.8 – 90 deg.
- To know final position, count number of pulses
- Velocity = No. of pulses per unit time
- 500 pulses/sec $\equiv$ 150 rpm (1.8^o/pulse)
- Pulses cease, motor stops. No brake, etc.
- Max. torque at low pulse rate
- Many steppers from same source.
- Perfect synchronization

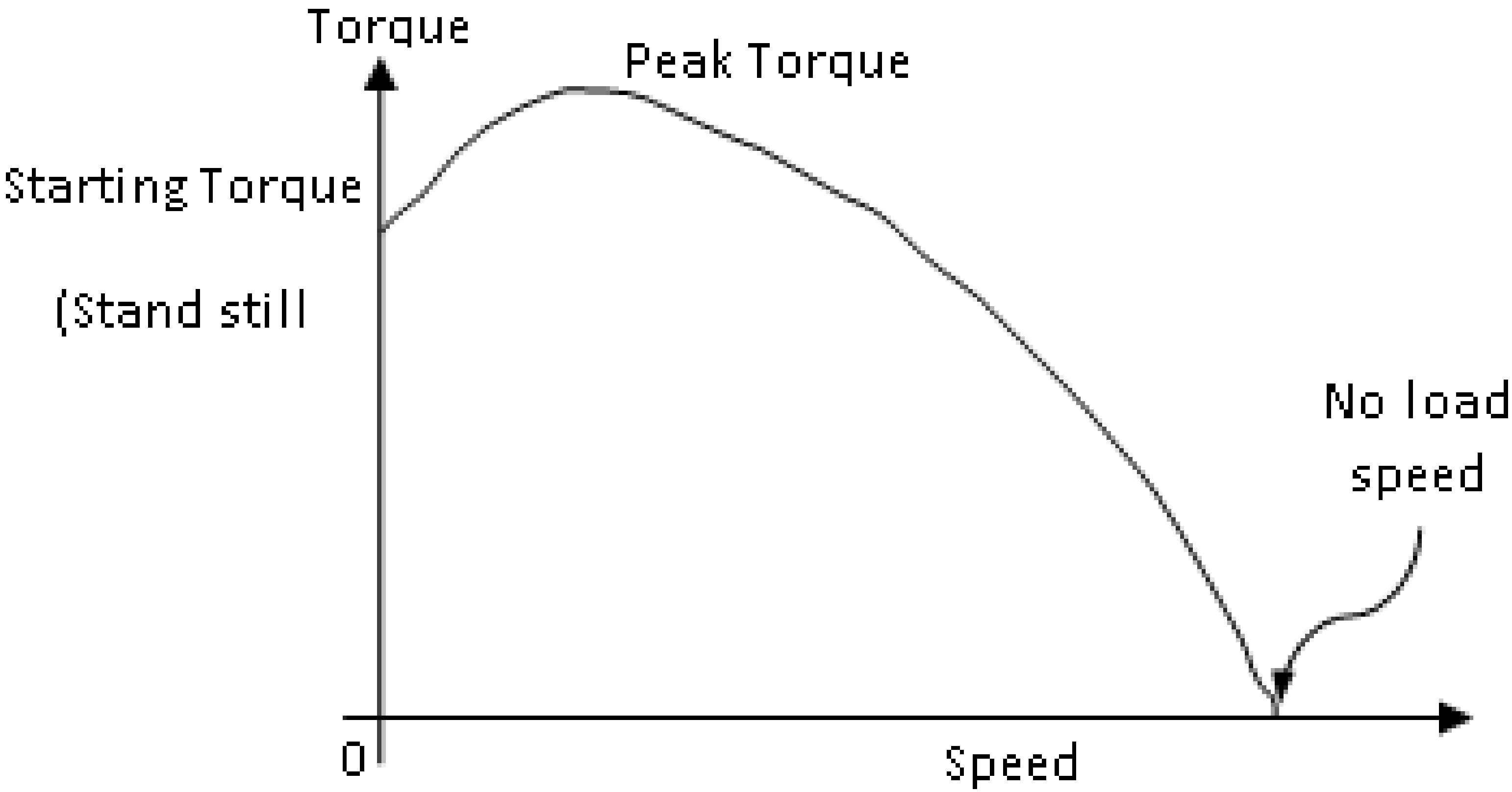
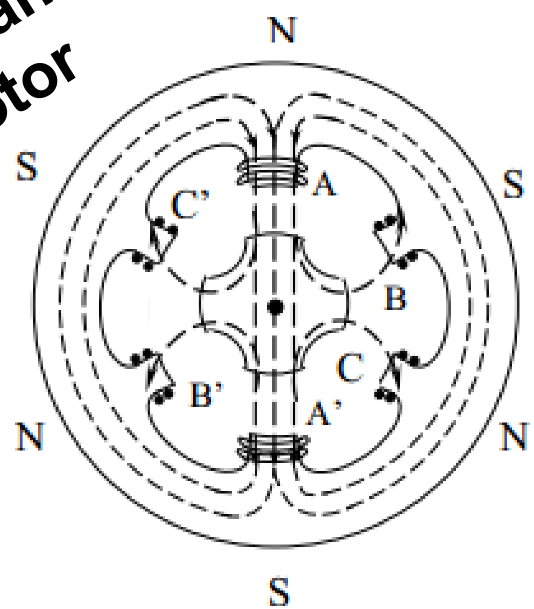


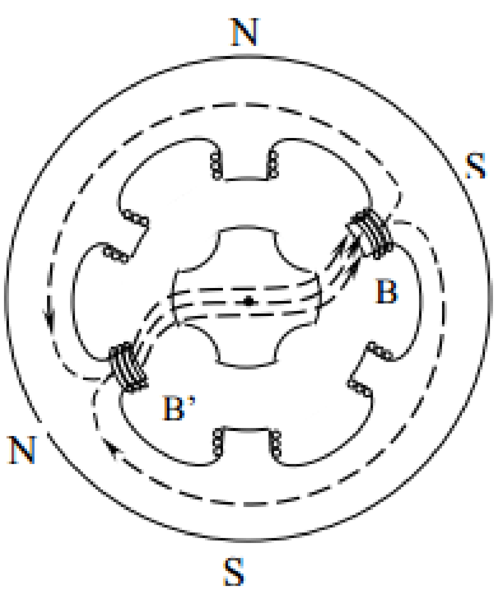
Fig. Torque-speed characteristics of a stepper motor

Variable Reluctance Stepper Motor

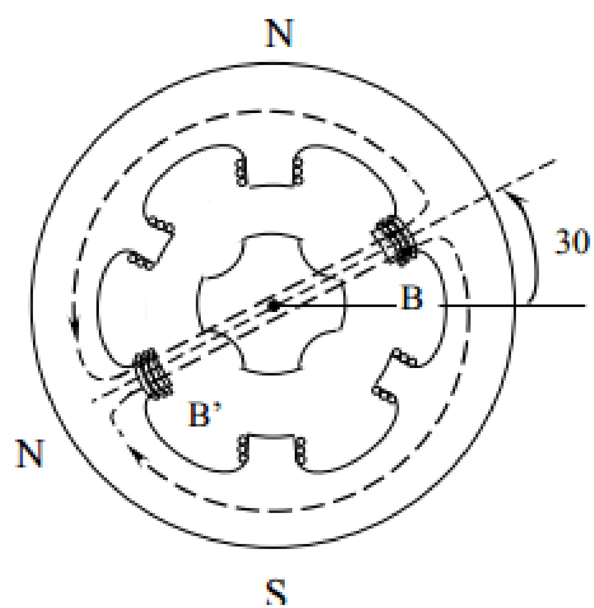


(a) Basic configuration

- Magnetic reluctance ≡ Elec. Resistance
- Magnetic flux only around closed path
- Rotor + stator teeth aligned with minimum reluctance → rotor is at rest
- To rotate, AA' is off BB' is on



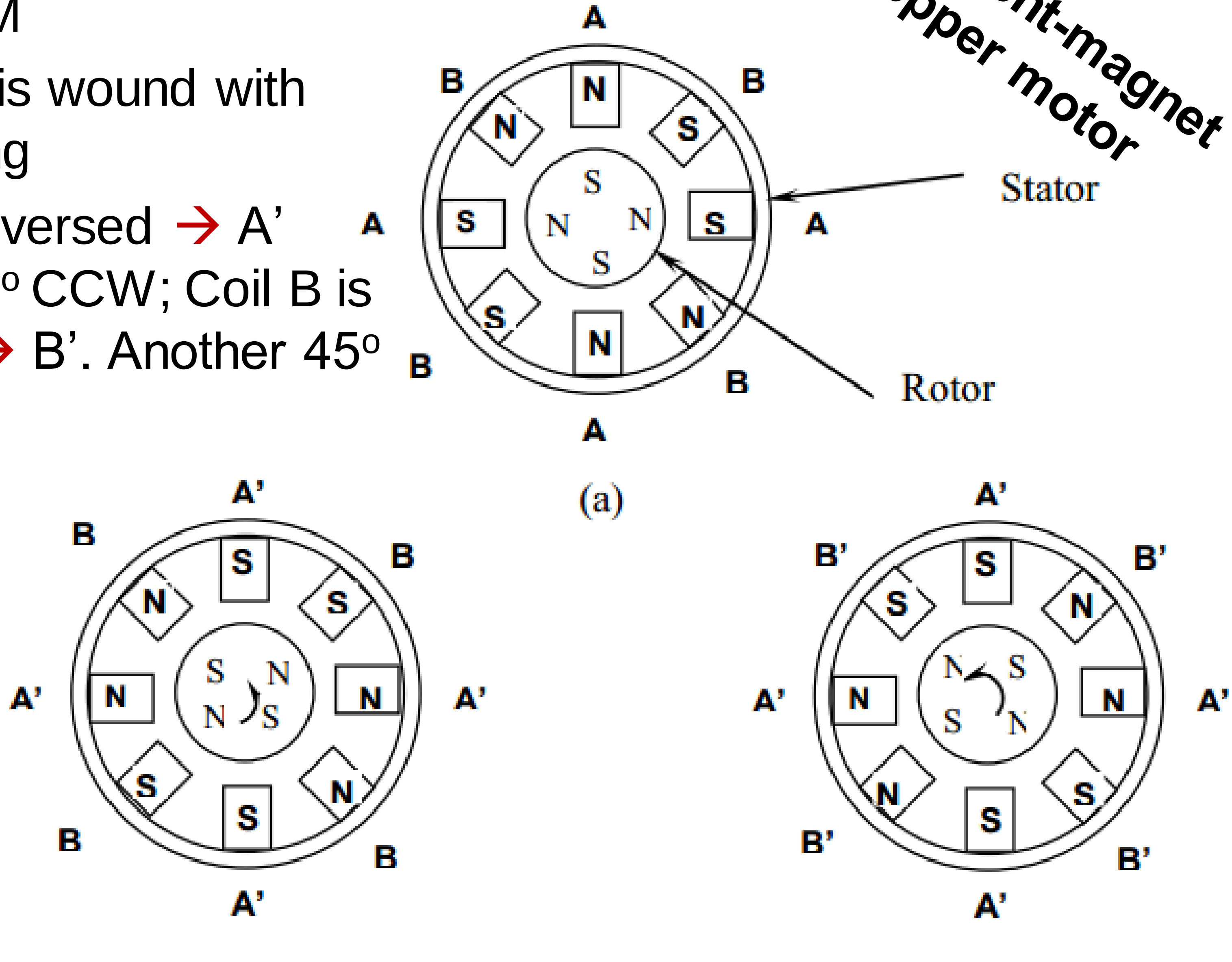
(b) Beginning of step



(c) Completed step

Permanent-magnet stepper motor

- Coil sets: A and B
- Rotor is PM
- Each pole is wound with field winding
- Coil A is reversed → A’ Rotates 45º CCW; Coil B is reversed → B’. Another 45º



(a)

(b)

(c)

Hybrid Stepper

- Combines the features of Variable Reluctance and Permanent Motor
- Permanent magnet with iron caps that have teeth
- The rotor sets itself in minimum reluctance position

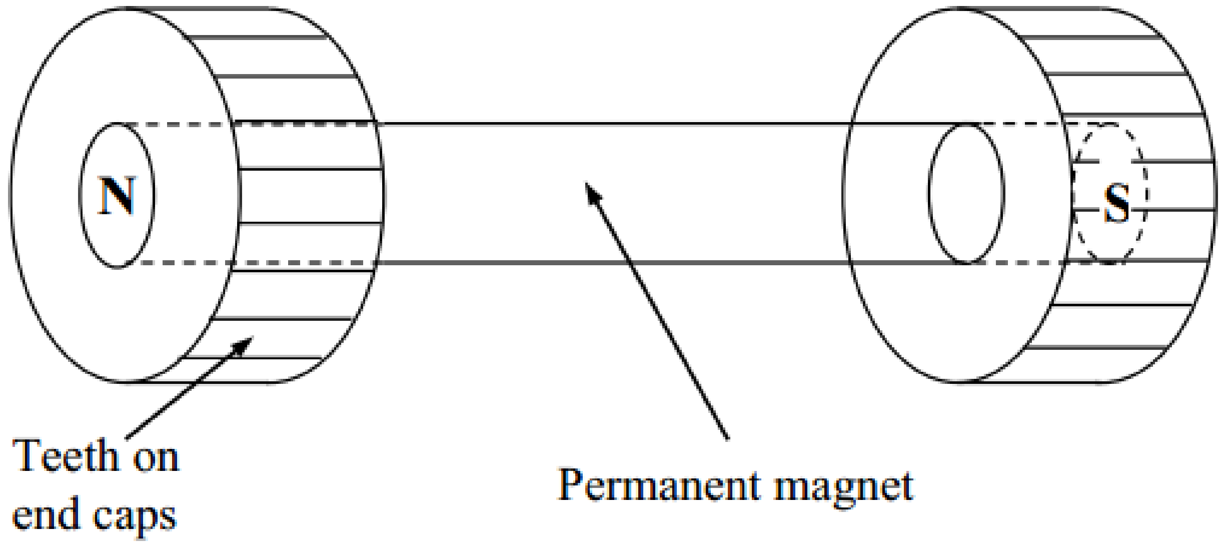


Fig. Permanent-magnet stepper motor

Example: Sequence for Full-step Angle

Table Full-stepping for a two-phase motor

Phase \ Step	1	2	3	4	Rotation
	→	→	→	→	CW
P_1	0	-1	0	1	
P_2	1	0	-1	0	
	←	←	←	←	CCW

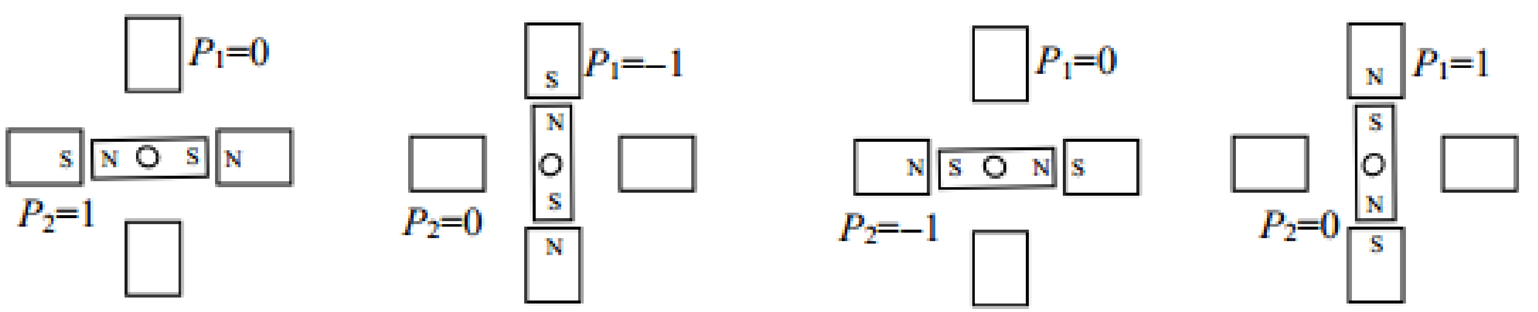
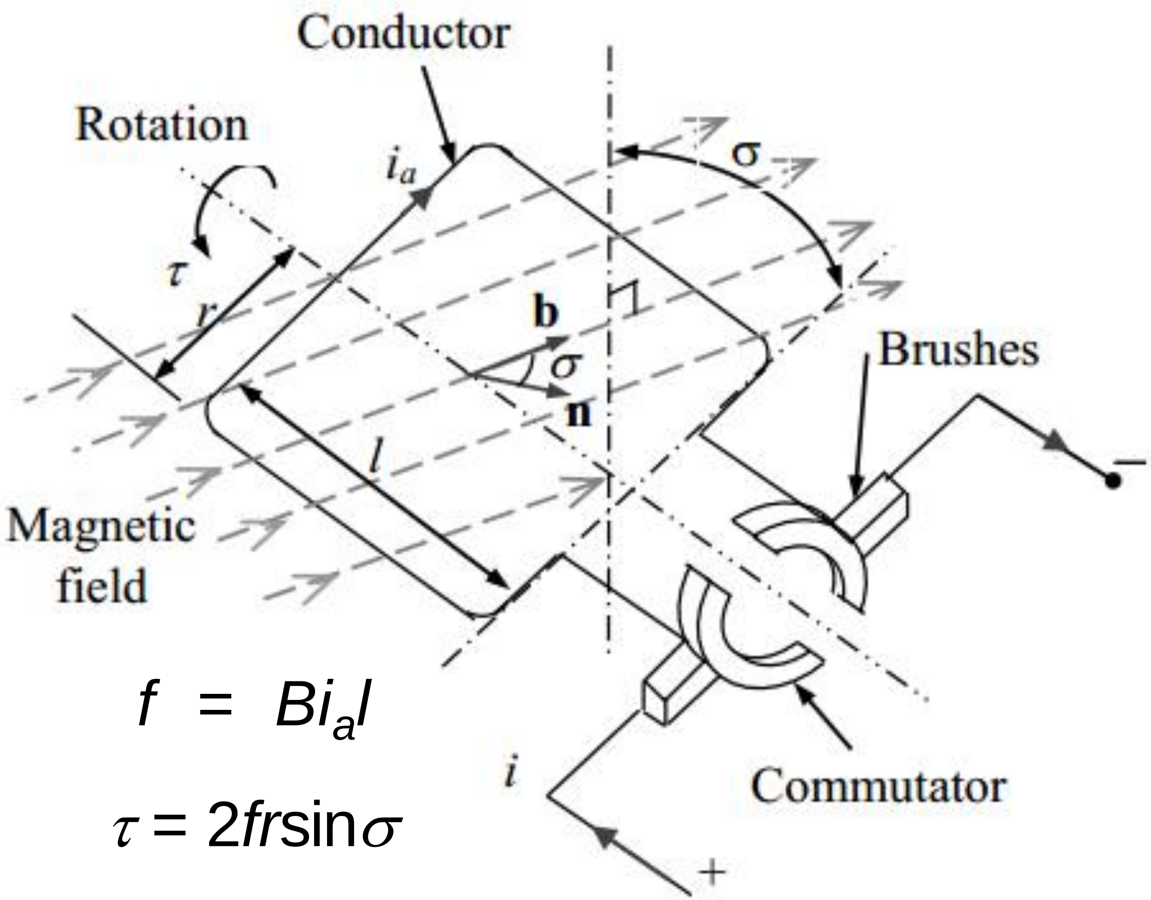


Fig. Stepping sequence

DC Motors

- Direct Current: Used in toys etc.
- Electrically driven robots use DC
  - Powerful versions available
  - Control is simple
  - Batteries are rarely used
  - AC supply is rectified to DC

- Magnetic Field → Stator Field coils wound on the stators
- Permanent magnet Conductor (Armature) → Rotor Current via brushes + commutators
- Maximum torque for $\sigma = 90^o$



$$f = Bi_a l$$

$$\tau = 2fr\sin\sigma$$

Fig. (a) Principle of a DC motor

Features of a DC Motor

- High voltage in stator coils → Fast speed (simple speed control)
- Varying current in armature → Controls torque
- Reversing polarity → Turns opposite
- Larger robots: Field control DC motor
  - Current in field coils → Controls torque
  - High power at high speed + High power/wt.

Specifications and Characteristics

Table Specifications of a DC motor [Courtesy: http://uk.rs-online.com]

Technical Specifications of DC Motors	
Brand	Parvalux
Manufacturer Part No.	PM2 160W511109
Type	Industrial DC Electric Motors
Shaft Size (S,M,L)	M
Speed (rpm)	4000 rpm
Power Rating (W)	160 W
Voltage Rating (Vdc)	50 V(dc)
Input Current	3.8 A
Height × Width × Length	78 mm ×140 mm × 165 mm

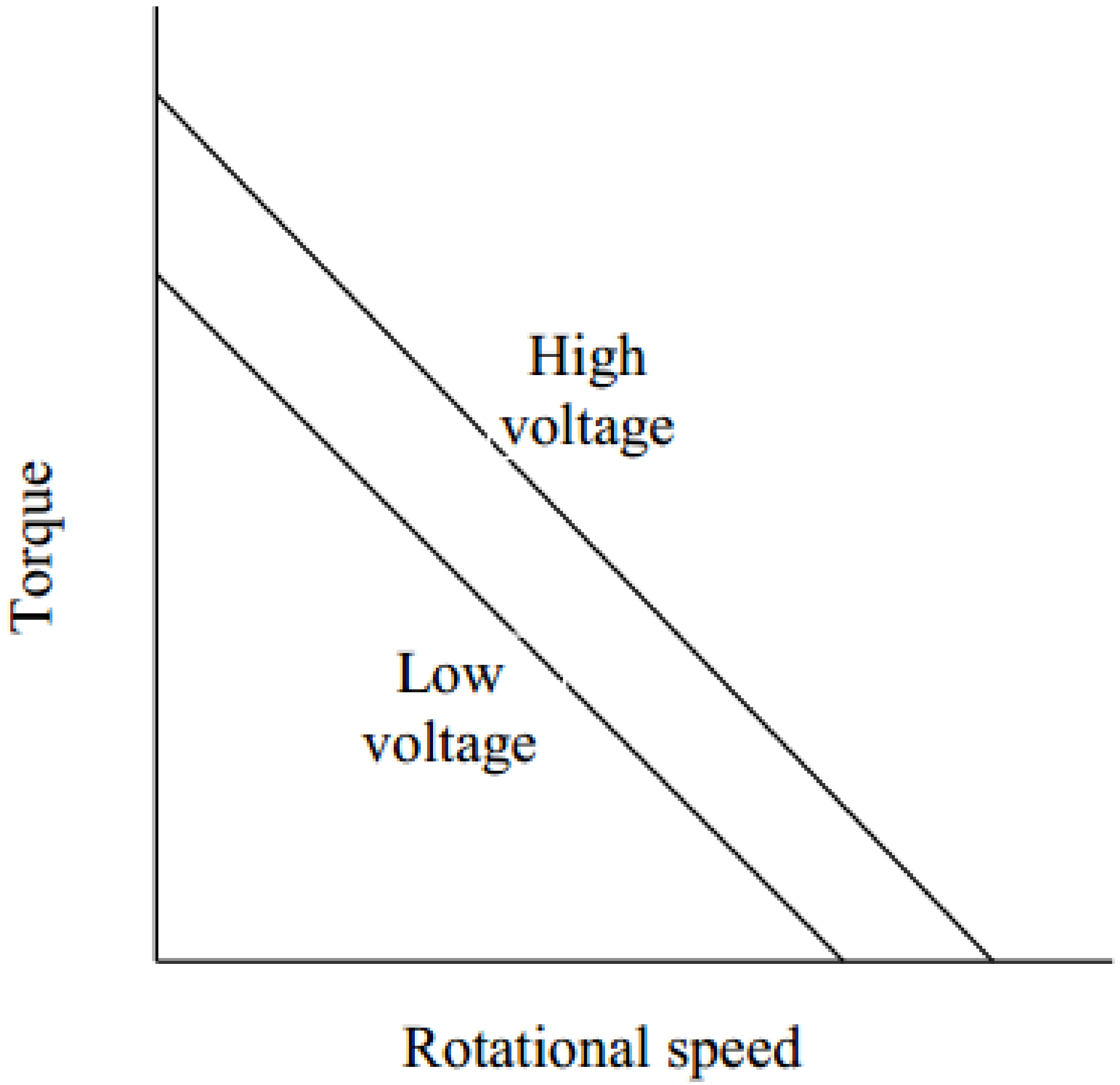


Fig. Speed-torque speed characteristics of a DC motor

Brushless PM DC Motor

- Problem with DC motors
  - Commuter and brushes → Periodical reversal of current through each armature coil
  - Brushes + Commutators → Sliding contact → Sparks → Wear → Change brushes + Resurface commutators
- Solution: Brushless motors
  - Sequence of stator coils
  - PM rotor

Principles of Brushless PM

- Reverse principle than conventional DC
- Current carrying conductor (stator) experience a force
- Magnet (rotor) will experience a reaction (Newton's 3rd law)
- Current to stator coils is electronically switched by transistors (Expensive)
- Switching is controlled by rotor position → Magnet (rotor) rotates same direction

Advantages of Brushless PM

- Better heat dissipation
- Reduced rotor inertia
- Weigh less → Less expensive + Durable
- Smaller for comparable power
- Absence of brushes → Reduced maintenance cost
- Quieter operation
- Lower mechanical loading

- Electric robots → Hazardous areas with flammable atmospheres (Spray painting)
- Improved safety

Disadvantages of Brushless PM

- Control system is relatively expensive.

Example: Stable and Unstable Operating Points of a DC Motor

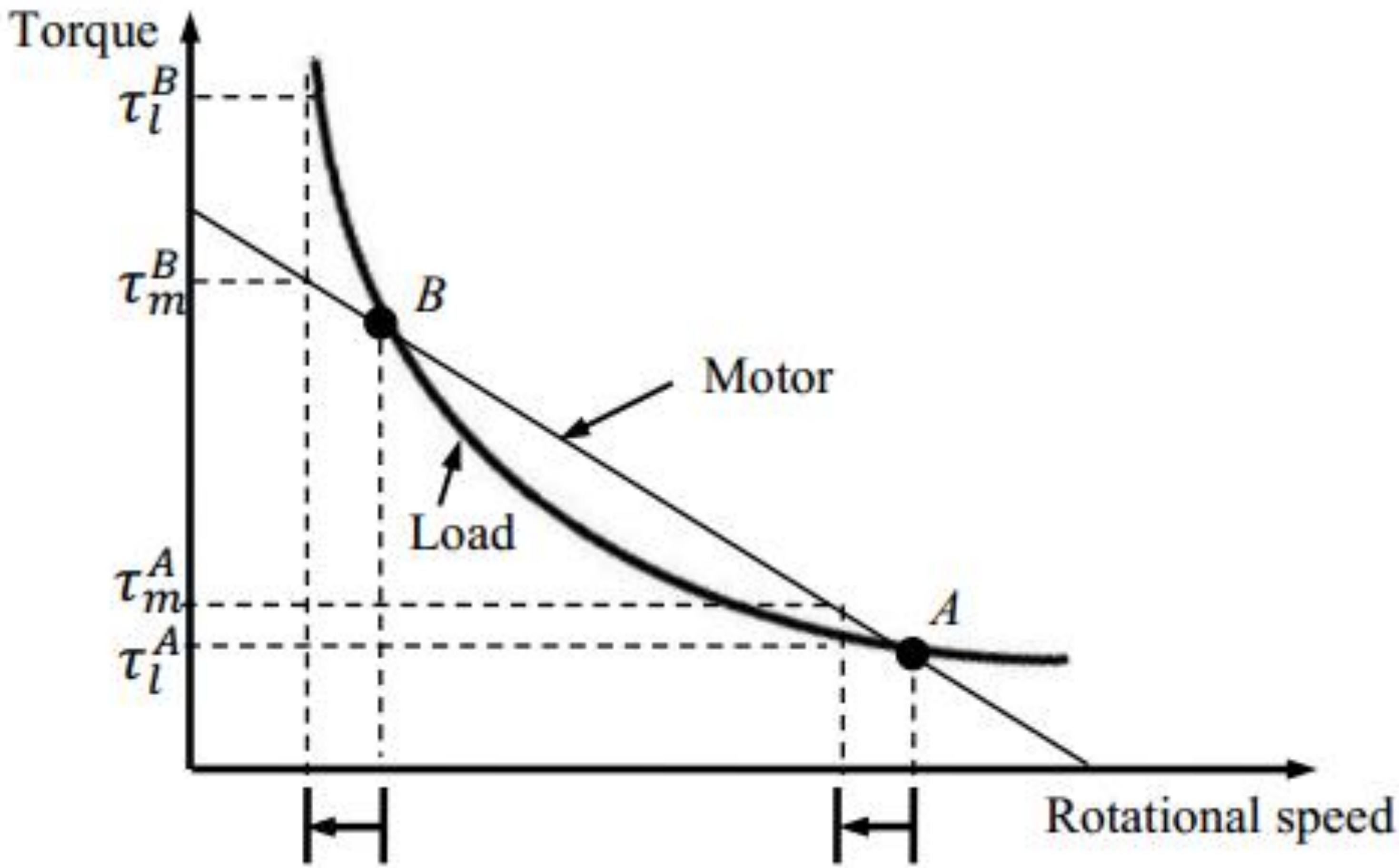


Fig. Steady-state characteristic curve of a DC motor

AC Motors

- Alternating Current: Domestic supply
- 50 Hz; 220 V (India)
- 60 Hz; 110 V (USA)
- Difficult to control speed → Not suitable for robots

Principle of an AC Motor

- External electromagnets (EM) around a central rotor
- AC supply to EM → Polarity change performs the task of mechanical switching
- Magnetic field of coils will appear to rotate → Induces current in rotor (induction) or makes rotor to rotate (synchronous)

AC vs. DC Motors

- Cheaper
- Convenient power supply
- Safer- no electric spark due to absence of commutator and brush
- Low power dissipation and low rotor inertia
- High reliability, robustness, easy maintenance, and long life.

AC vs. DC Motors (Contd.)

- Low starting torque.
- Need auxiliary devices to start.
- Speed control is more complex.
- Speed-controlled DC drive (stator voltage) is cheaper than speed-controlled AC drive (Variable Frequency Drive)
- Price of VFD is steadily reducing

Specifications and Characteristics

Table Specifications of an AC motor [Courtesy: http://uk.rs-online.com]

Technical Specifications of AC Motor	
Brand	ABB
Manufacturer Part No.	1676687
Type	Industrial 1-, 3-Phase Electric Motors
Supply Voltage	220 – 240 Vac 50 Hz
Output Power	180 W
Input Current	0.783 A
Shaft Diameter	14 mm
Shaft Length	30 mm
Speed	1370 rpm
Rated Torque	1.3 Nm
Torque Starting	1.3 Nm
Height × Length × Width	150 mm × 213 mm × 120 mm

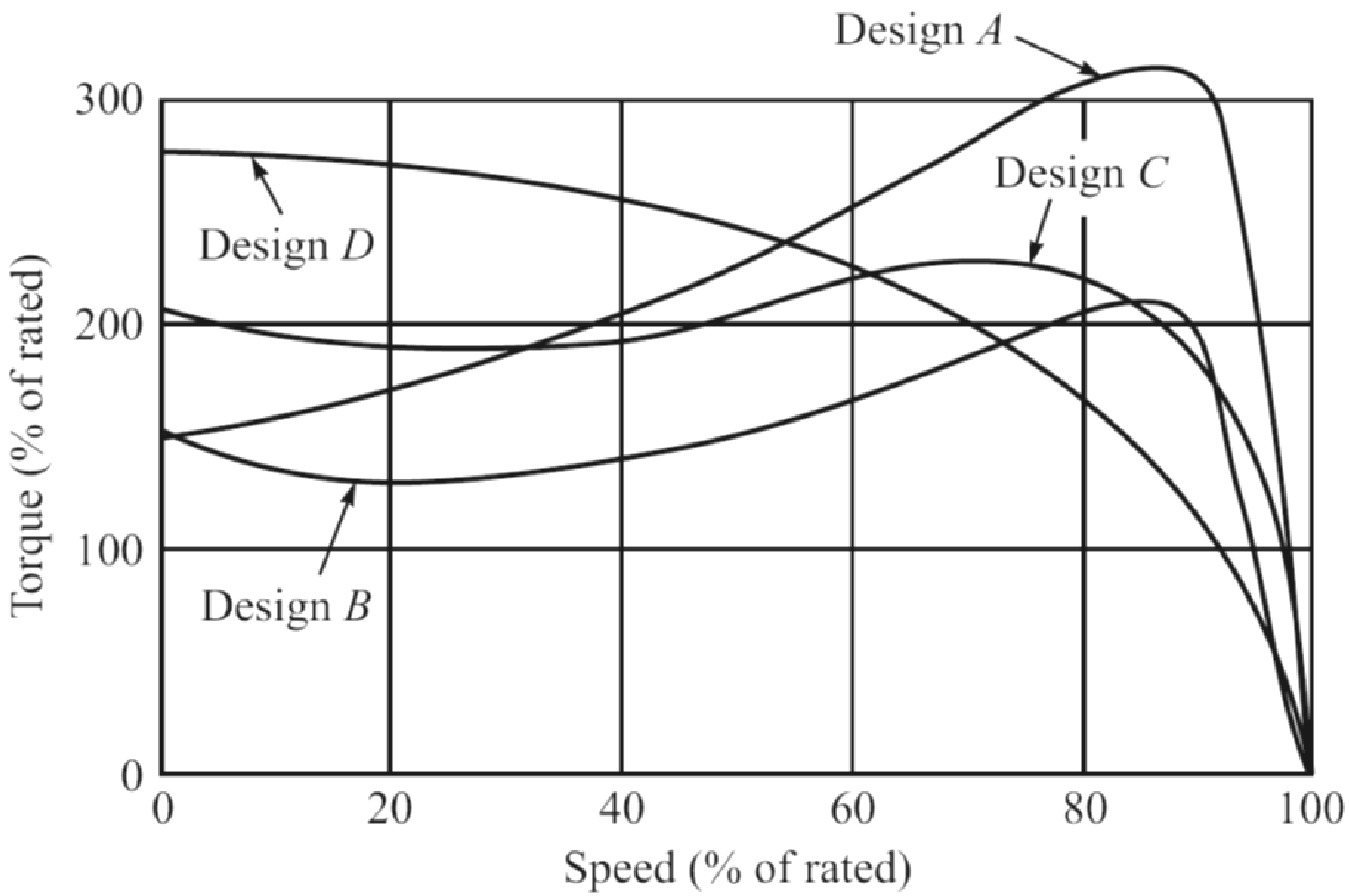


Fig. Typical speed-torque characteristics for four different designs of an AC induction motor

[Courtesy: www.electricmotors.machinedesign.com/guiEdits/Content/bdeee11/bdeee11_7.aspx]

Features of an AC Motor

- Higher the frequency → Fast speed
- Varying frequency to a number of robot axes has been impractical till recently
- Electromagnetism is used for regenerative braking (also for DC) → Reduces deceleration time and overrun
- Motor speed cannot be predicted (same for DC) → Extra arrangements required

Classification of an AC Motor

- Single-phase [Low-power requirements]
  - Induction
  - Synchronous
- Poly-phase (typically 3-phase) [High-power requirements]
  - Induction
  - Synchronous
- Induction motors are cheaper → Widely used

Linear Actuators

- Solenoid based linear actuators for on-off operations of the gripper and other devices.
- Solenoids are rugged and inexpensive.
- Electrically powered rotary motors coupled with transmission mechanisms (nut and ball-screw, cam-follower, rack-and-pinion).
- Friction and backlash

Hydraulic Actuators

- One of fluid power devices
- Uses high-pressure fluid [70 -170 bar]
- Four Components
  1) Reservoir;
  2) Pumps;
  3) Valves;
  4) Actuator.

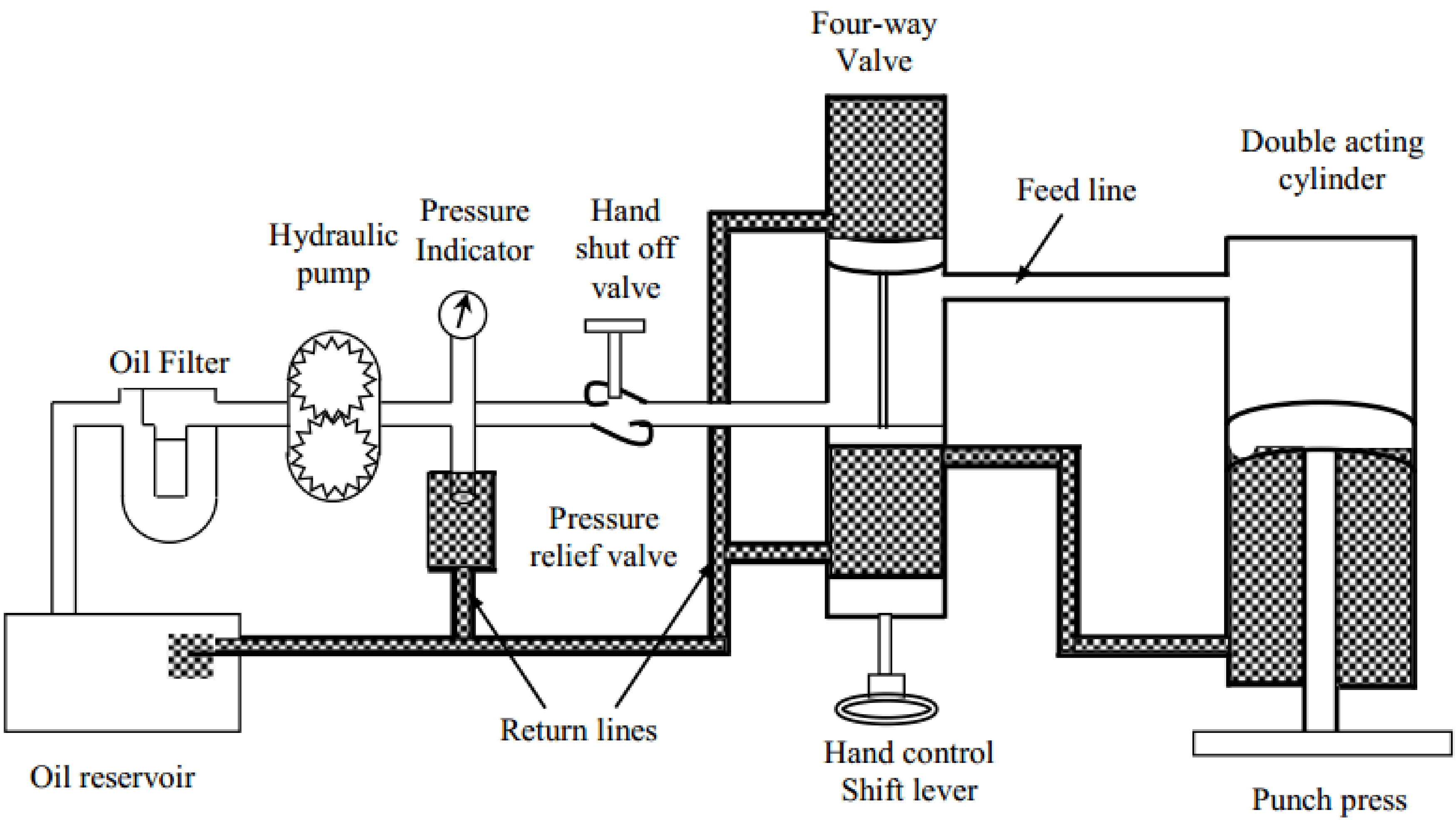
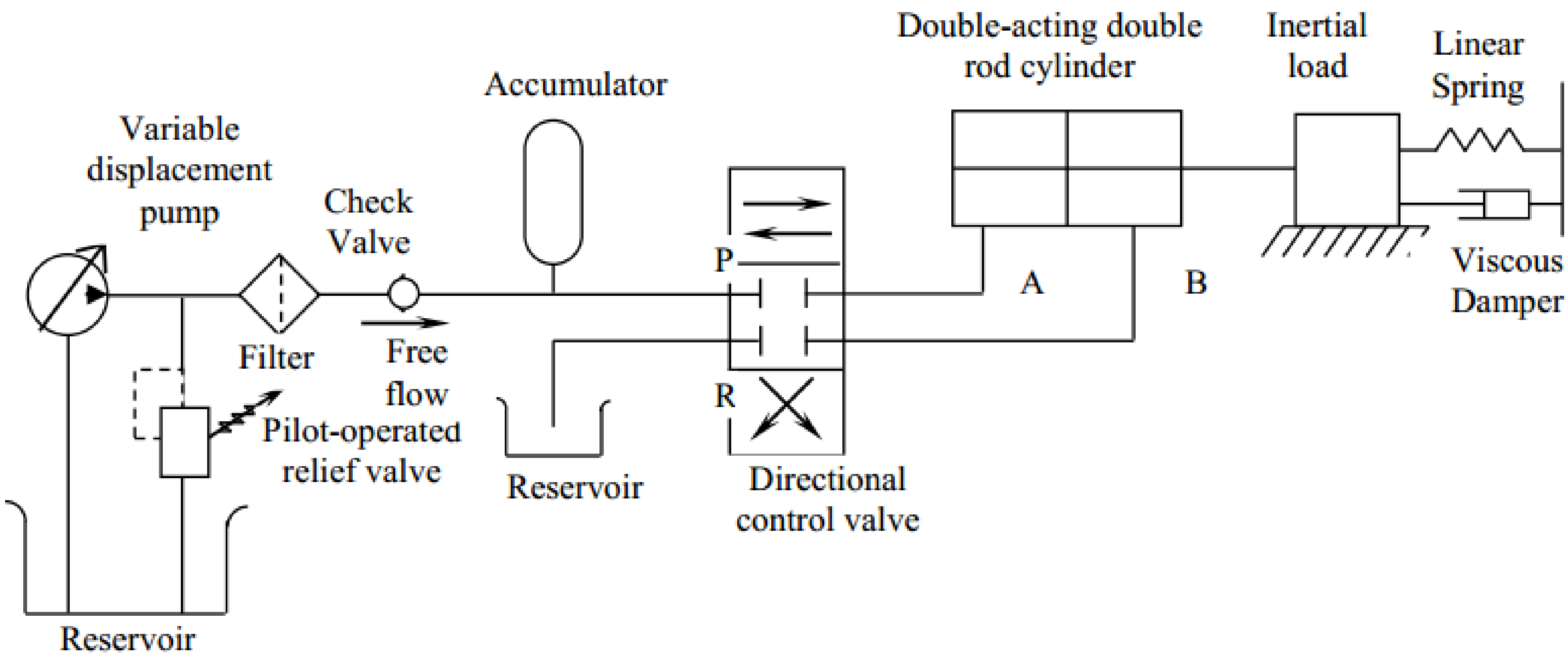


Fig. (a) Hydraulic actuator components



(b) Hydraulic circuit [Courtesy: Stadler (1995)]

Fig. A hydraulic actuator

Fig. (a) Hydraulic cylinder
[Courtesy: www.meritindustriesltd.com]

Advantages vs. Disadvantages

- *Advantages*
  - High η + power-to-size ratio.
  - Accurate control of speed/pos./dirn.
  - Few backlash prob. ⇐ Stiffness + incompressibility of fluid
  - Large forces can be applied at locations.

Backlash ≡ Unwanted play in transmission components

- Greater load carrying capacity
- No mechanical linkage → Mechanical simplicity.
- Self lubricating → Low wear + non-corrosive
- Due to 'storage' sudden demands can be met.
- Capable of withstanding shock.

- *Disadvantages*
  - Leakages occur → Loss in performance
  - Higher fire risk.
  - Power pack is (70 dBA)
  - Temp. change alters viscosity.
  - ↑Viscosity at↓ temp. causes sluggishness.
  - Cost of hydraulic components do not decrease in proportion to size.
  - Servo-control is complex

70 dbA ≡ Noise of heavy traffic

Pneumatic Actuators

- One of fluid devices
- Uses compressed air [1-7 bar; ~.1 MPa/bar]
- Components

  1) Compressor; 2) After-cooler; 3) Storage tank;

  4) Desiccant driers; 5) Filters; 6) Pressure regulators; 7) Lubricants; 8) Directional control valves; 9) Actuators

Fig. (b) Pneumatic cylinder
[Courtesy: www.festo.com]

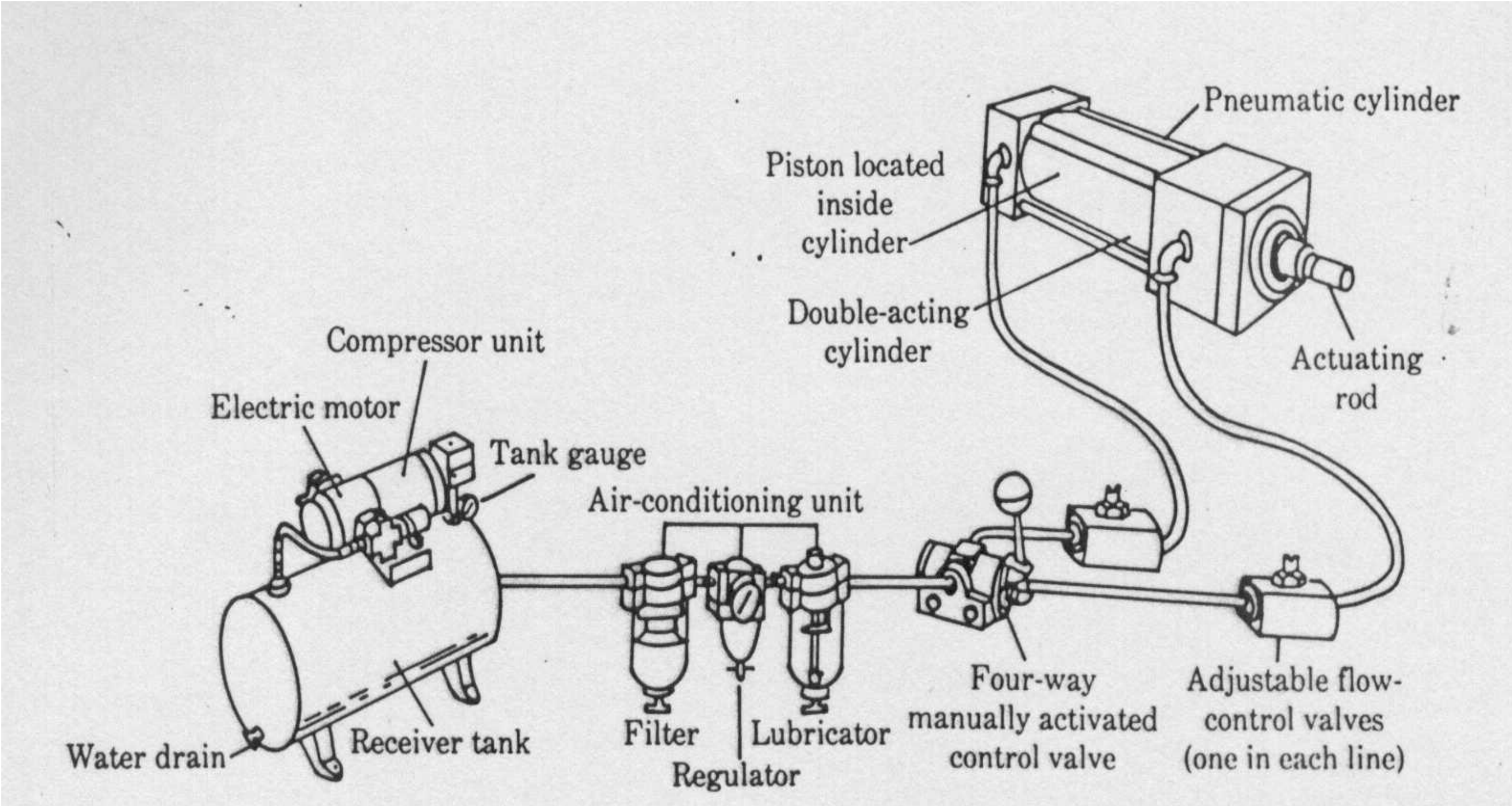


Fig. (a) Pneumatic actuator components

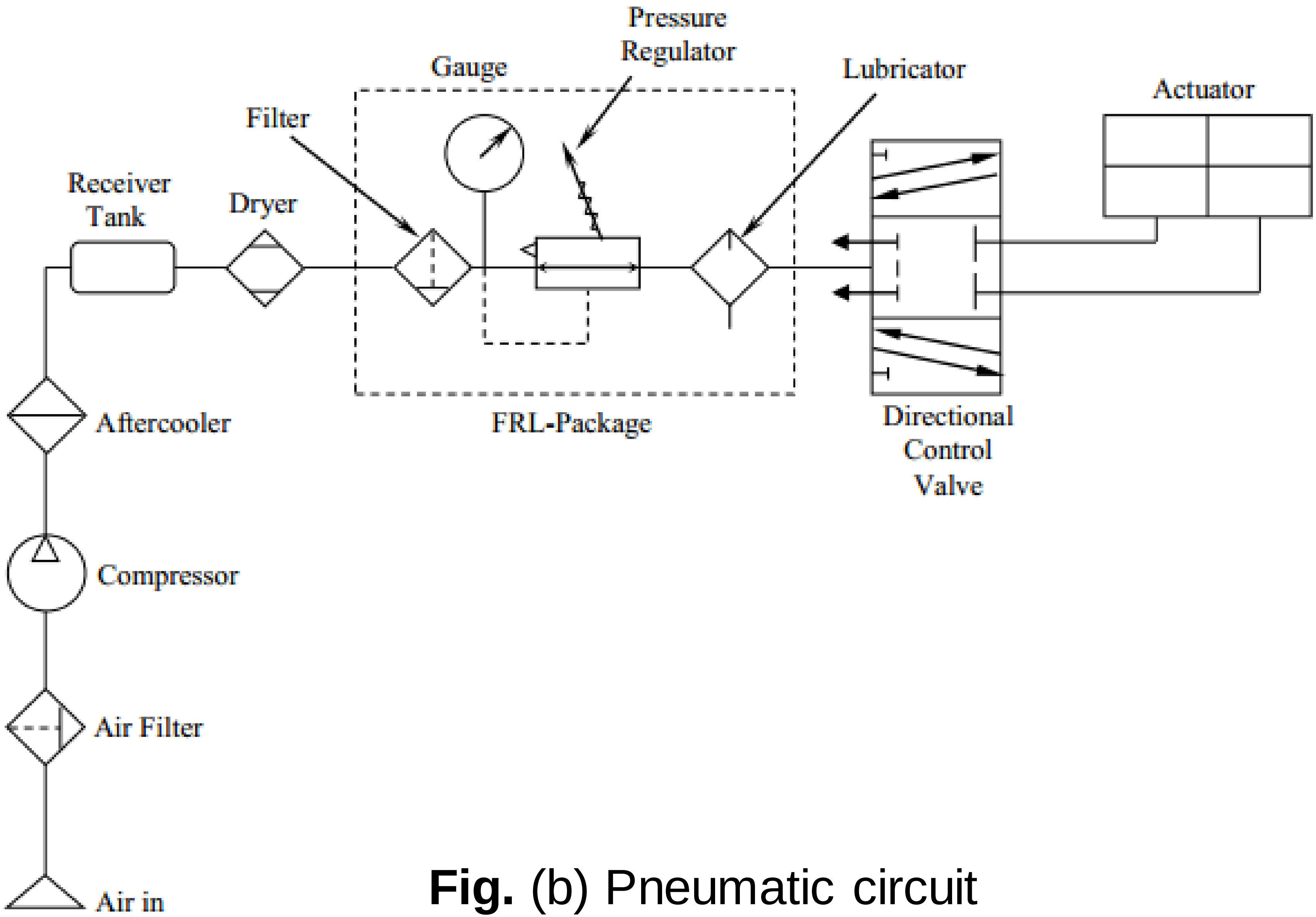


Fig. (b) Pneumatic circuit
[Courtesy: Stadler (1995)]

Advantages vs. Disadvantages

- *Advantages*
  - Cheapest form of actuators.
  - Components are readily available.
  - Compressed air is available in factories.
  - Compressed air can be stored, and conveyed easily over long distances.
  - Compressed air is clean, explosion-proof and insensitive to temp. var. ⇨ Many applns.

- Few moving parts → Reliable + low maintenance costs
- Relevant personnel are familiar with the tech.
- Very quick → Fast work cycles
- No mechanical transmission is required.
- Safe in explosive areas as no electrical contact
- Systems are compact.
- Control is simple. Mechanical stops.
- Components are easy to connect.

- *Disadvantages*
  - Air is compressible.
  - Precise control of speed/position is not easy.
  - If **no m**echanical stops resetting is slow.
  - Not suitable for heavy loads
  - If moisture penetrates rusts occur.

Compressibility of the air can be advantageous.

Prevents damage due to overload.

Purpose of a Sensor

- Sensors are like
  - Eyes, Skin, Nose, Ears, and Tongue
  - Terms like vision, tactile, etc. have emerged
- Gather information → To function effectively
  - During pick-n-place, obstacles are to be avoided
  - Fragile objects not to be broken
- End-effector, sensor, controller work together

Capabilities

- Simple Touch
  - Presence/absence of an object
- Traction or Complex Touch
  - Presence of an object
  - Size and shape
- Simple Force
  - Force along a single axis
- Complex Force
  - Along 2 or more axes

Capabilities …

- Proximity
  - Non-contact detection
- Simple Vision
  - Detects edges, holes, corners, etc.
- Complex Vision
  - Recognize shapes

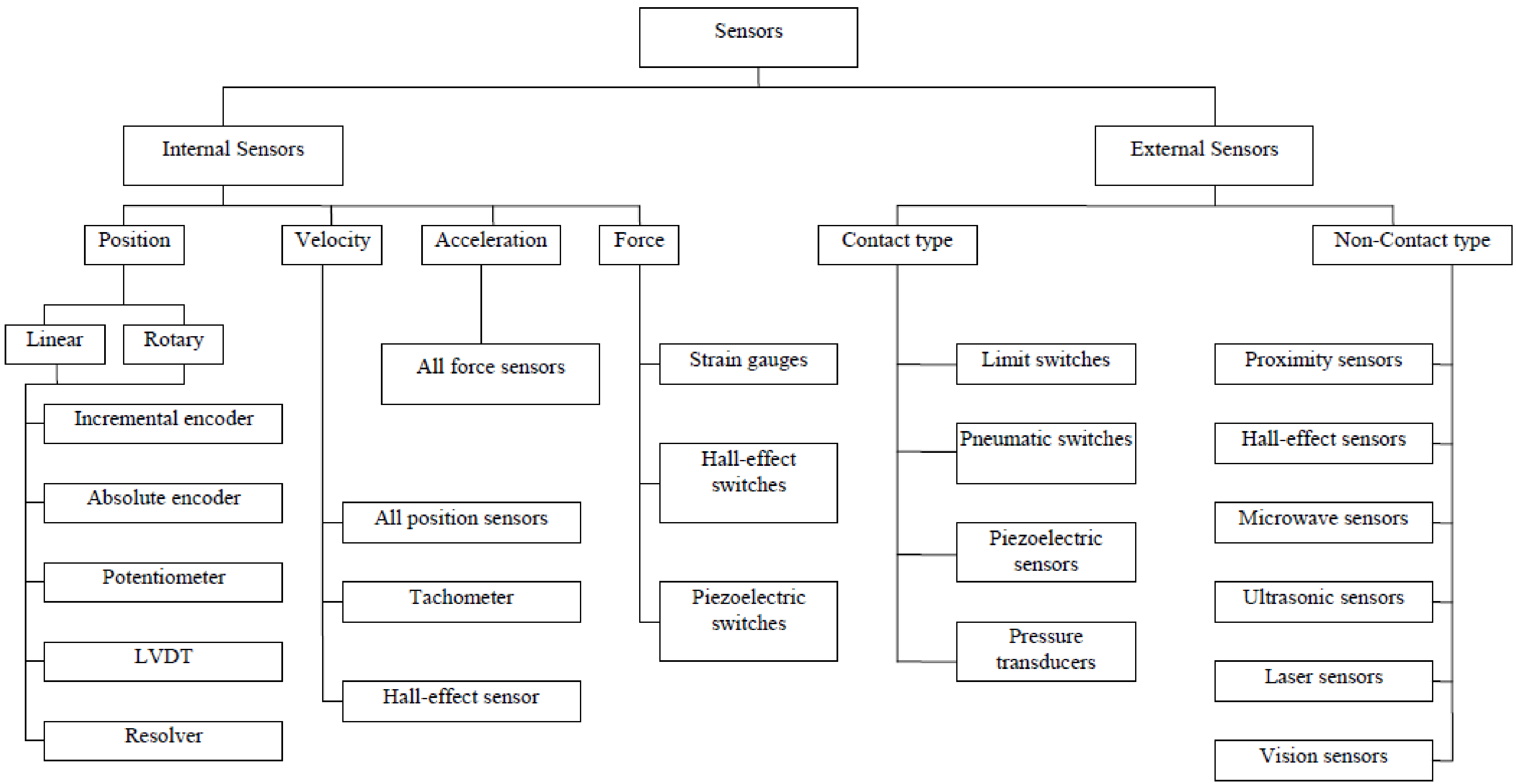


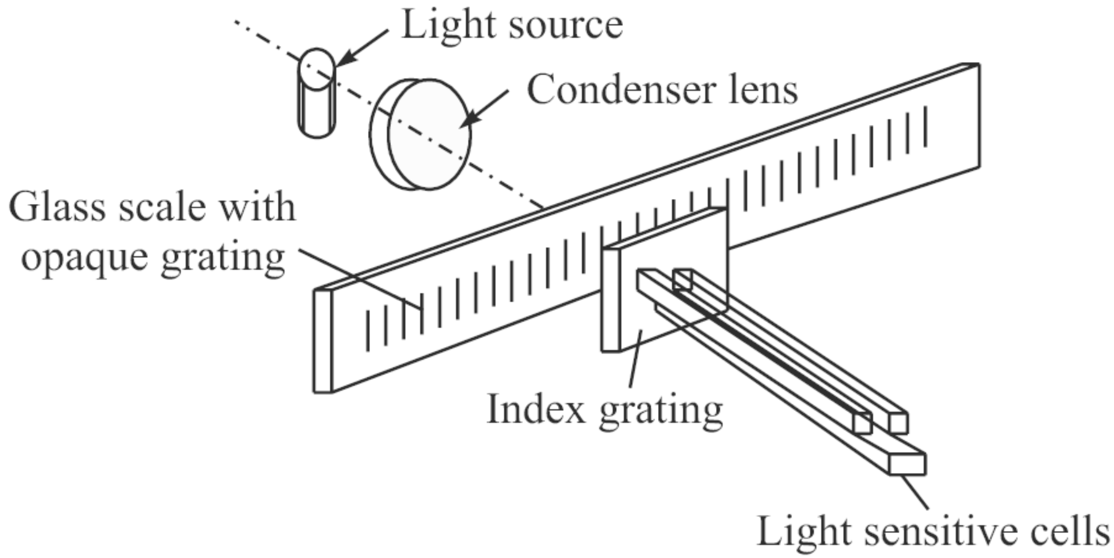
Fig. Classification of sensors

Internal Sensors

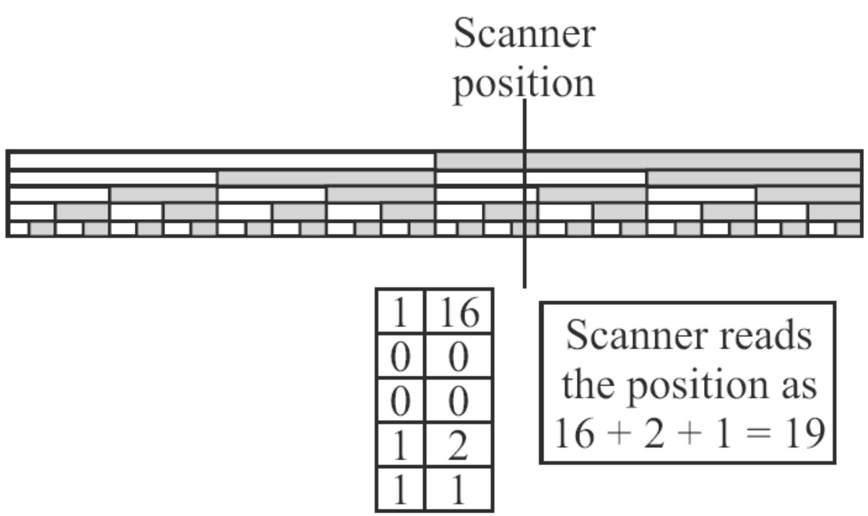
- Used to measure the internal state of a robot
  - Position
  - Velocity
  - Acceleration, etc
- Based on above info. control command is decided by controller

Position Sensors

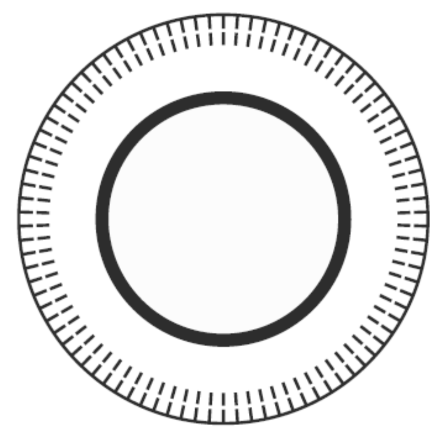
- Measures position (angle) of each joint
- Joint angles → End-effector configuration
- Encoder
  - Digital optical device
  - Converts motion → Sequence of pulses
  - Pulses can be converted to rel./abs. meas.
  - Incremental or Absolute
  - Linear and Rotary



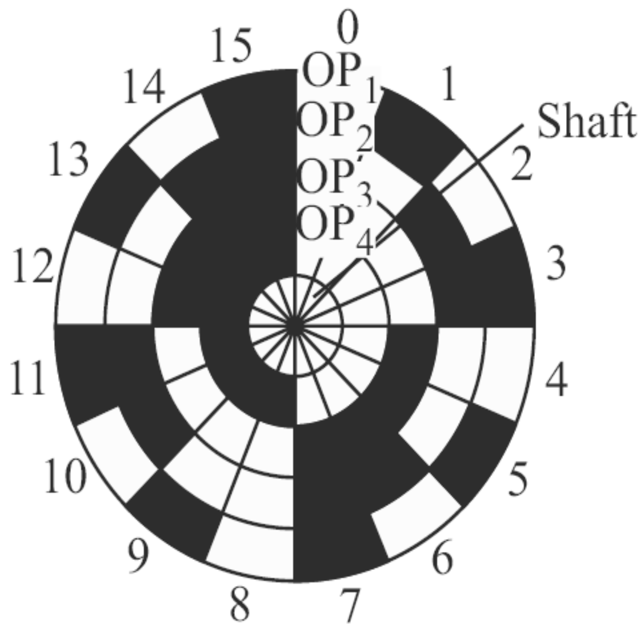
(a) Incremental linear type



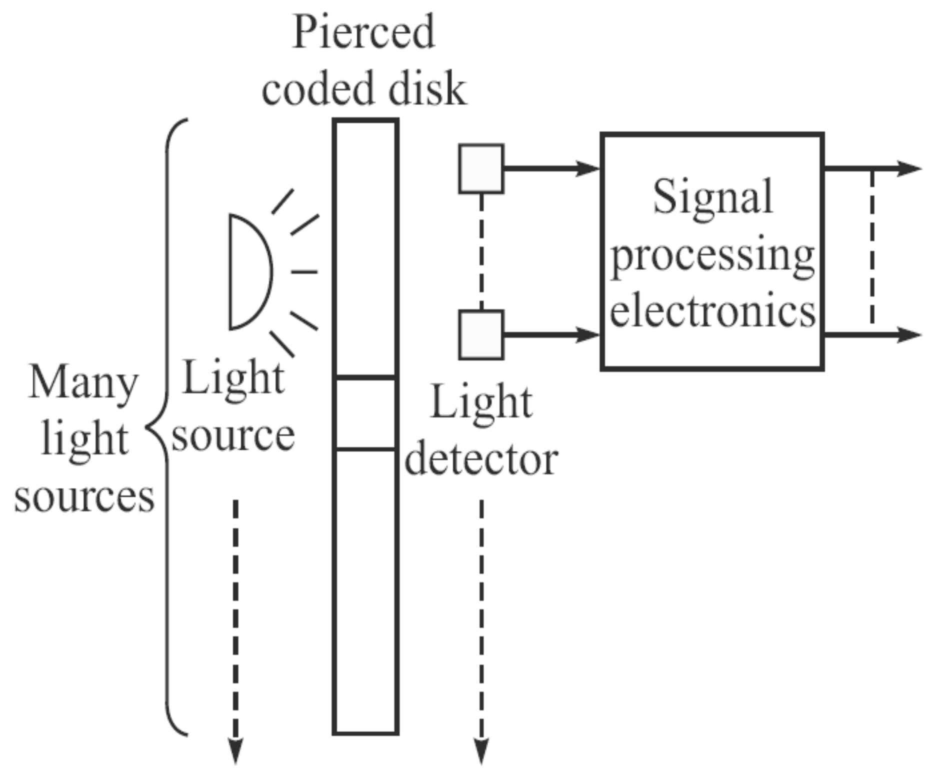
(b) Absolute linear type



(c) Incremental rotary type



(d) Absolute rotary type



(e) Rotary encoder

Incremental Rotary Encoder

- Gratings are on circular disc
- Common value of transparent, space width = 20 μm
- Two sets of grating lines on two different circles
  - Detects the direction of motion
  - Accuracy can be enhanced

Absolute Rotary Encoder

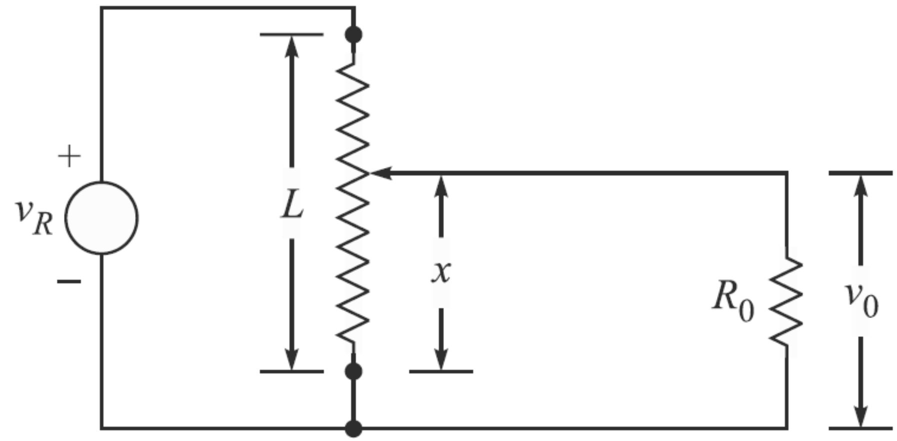
- Circular disk
  - Divided into a no. of circular strips
  - Each strip has definite arc segment
- Directly provides digital output
- Mounted on motor shaft or with some gearing (to enhance accuracy)

Absolute Rotary Encoder …

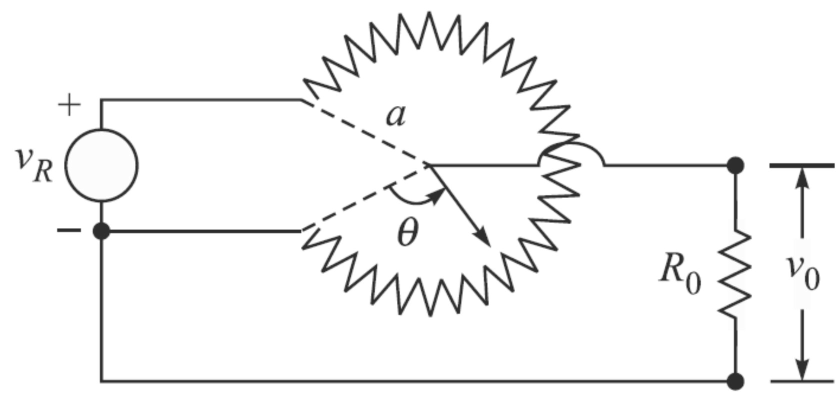
- A gray scale is sometimes used
  - To avoid noise
- Gray Code
  - Unlike binary code, allows only one binary bit of a code to change between radial lines
  - Prevents confusion in the changes of binary output of absolute encoder

Potentiometer

- Also referred as ‘pot’
- Variable resistance device
- Expresses linear/angular displacements in terms of voltage
- Consists of a wiper → Makes contact with resistive element
- When point of contact moves → Resistance between wiper and end leads change $\propto$ disp.



(a) Linear type



(b) Rotary type

v_R: Reference voltage; v_0: Measured voltage

L, x, R_0, a, θ: Other physical parameters

Fig. Potentiometers

LVDT

- Linear Variable Differential Transformer
- Widely used displacement transducer when high accuracy is required
- It generates AC signal. Magnitude is related to the moving core displacement
- Ferrous core moving a magnetic field
- Field is created similar to transformer

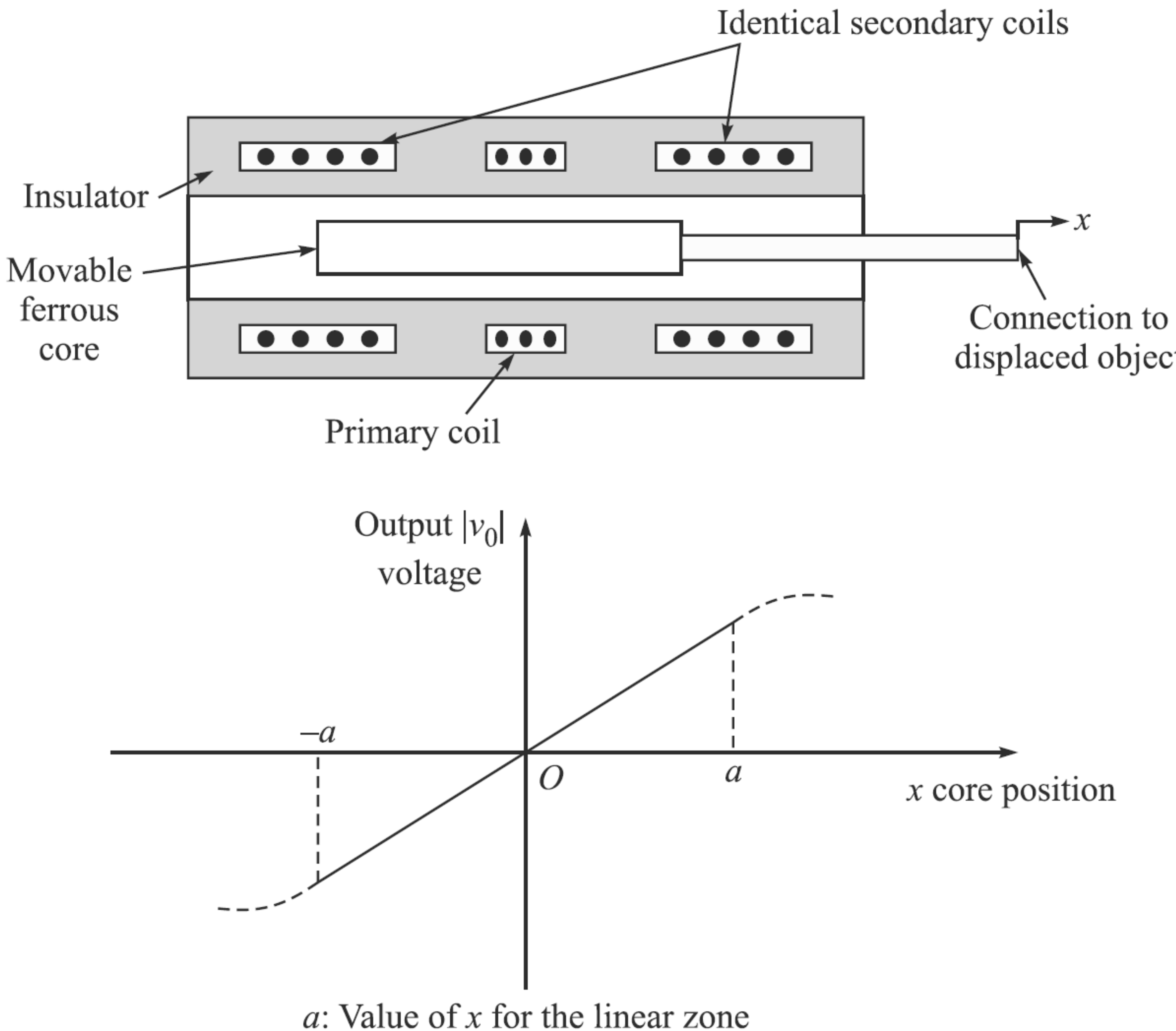


Fig. Principle of LVDT

LVDT …

- Central core surrounded by two identical secondary coils and a primary coil
- As core changes its position w.r.t. coils it changes the magnetic field
- Voltage amplitude in secondary coil changes as a function of core displacement
- An RVDT uses same principle for rotation
  - Available for range of $\pm 40^{o}$

Velocity Sensors

- All position sensors with certain time bounds
- Velocity = No. of pulses for an incremental encoder divided by time consumed in doing so
- This scheme puts some computational load on controller

Tachometer

- Finds speed directly without any computational load
- Based on Fleming's rule: Voltage produced $\propto$ Rate of change of flux linkage
- Voltage produced $\propto$ Speed of shaft rotation
- Information to be digitized using ADC before passing it to the controller computer

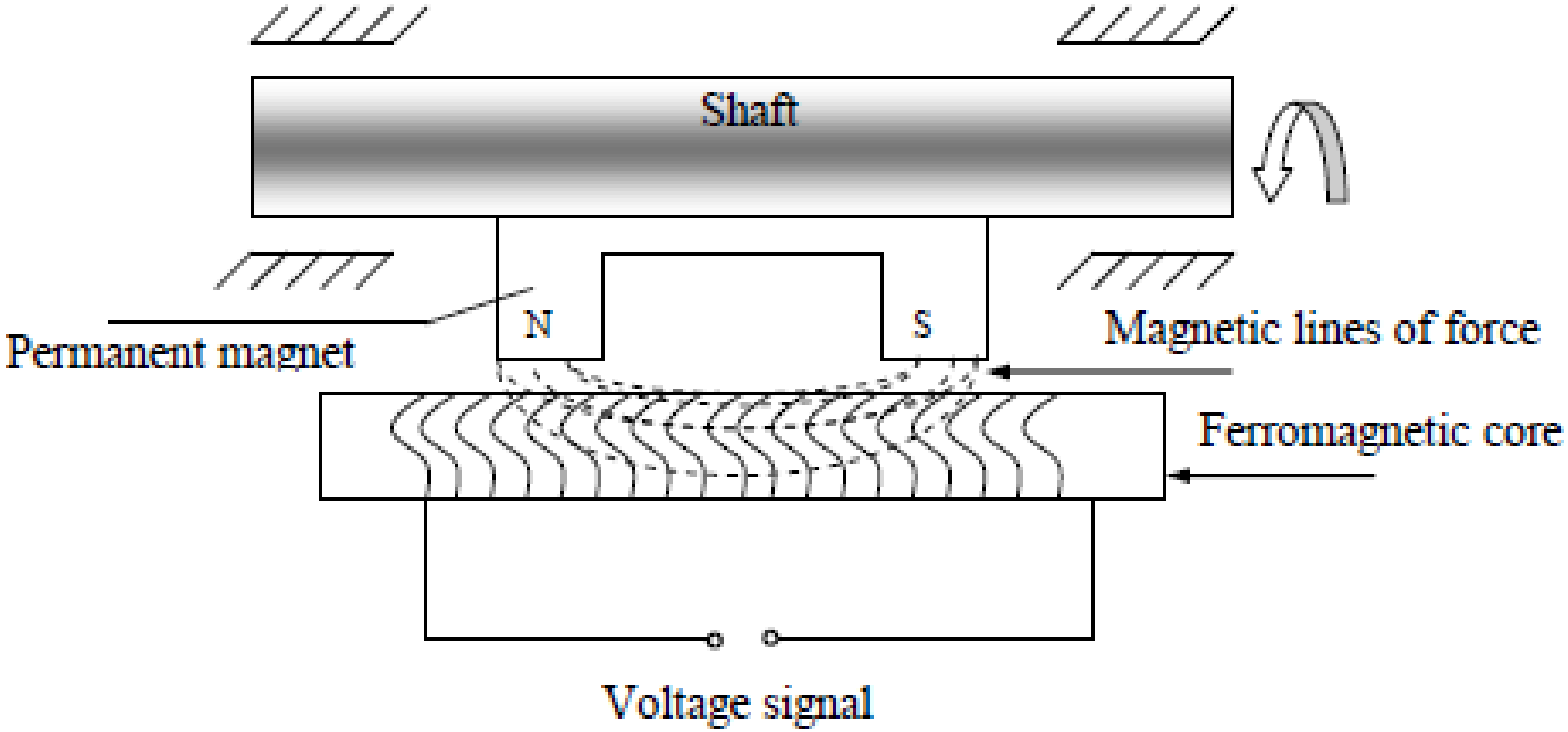


Fig. Schematic diagram of a tachometer

Acceleration Sensors

- Time-rate of change of velocities or double time-rate of change of positions
- Heavy computational load on the computer → Not efficient
- Speed of robot operation will be hampered
- Alternate way: Measure force (F) = mass (m) x acceleration (a)

Acceleration Sensors …

- Force can be measured using strain gauges

$$F = \Delta R \, A \, E /(R \, C)$$

F: Force; ΔR: Change in resistance of strain gauge (SG); A: Area; E: Elastic modulus of SG material; R: Original resistance of SG; C: Deformation constant of SG

Acceleration, $a = F/m = \Delta R \, A \, E /(R \, C \, m)$

Differentiation vs. Integration

- Velocity and acceleration using a position sensor requires differentiation → Not desired
- Any noise is amplified upon differentiation
- Velocity and position from acceleration require integration → Recommended
- Integrators tend to suppress noise

Force Sensors

- A spring balance is a force sensor
- Force (weight) is applied on scale pan → Displacement (spring stretches)
- Strain Gauge based, Piezoelectric, etc.

Strain Gauge

- Principle: Elongation of a conductor increases its resistance. Due to
  - Increase in length
  - Decrease in area
- Typical resistance 50-100 Ω
- Made of electrical conductors (wire or foil etched on base material

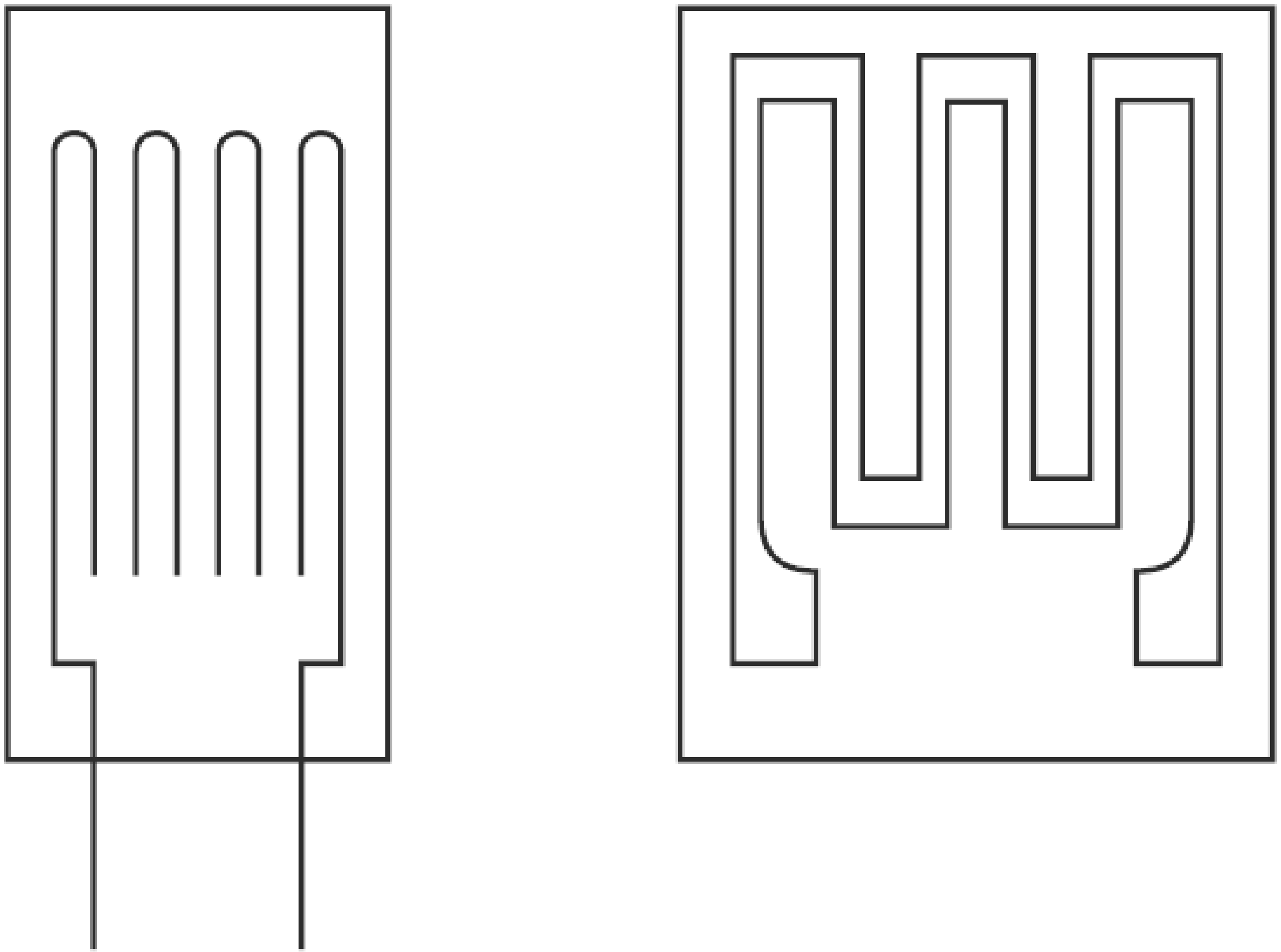
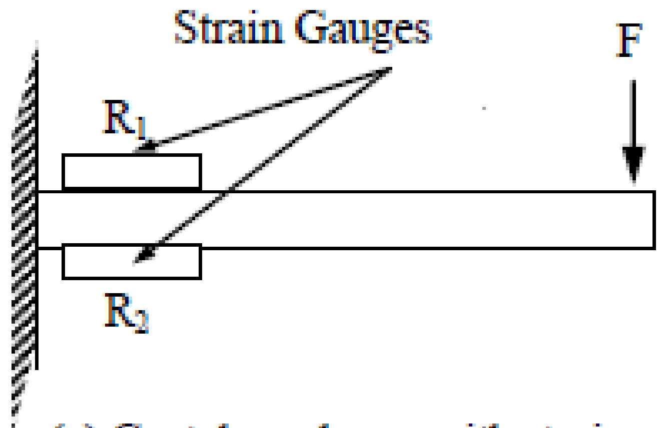


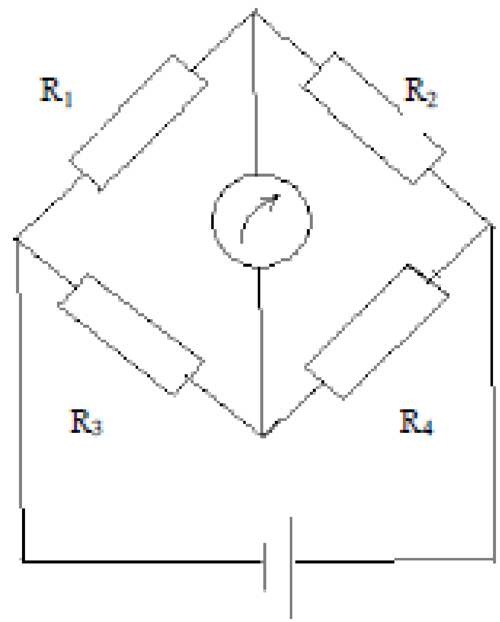
Fig. Strain gauges

Strain Gauge …

- Glued on surfaces where strains are measured, R_1 and R_2
- Resistances are measured by attaching them to the Wheatstone bridge circuit
- Cheap and accurate method
- Care should be taken for the temp. change
- To enhance output + temperature compensation 2 SGs are used



(a) Cantelever beam with strain gauges



(b) Wheatstone bridge circuit

Fig. Strain measurement

Piezoelectric Sensor

- Based on Piezoelectric effect
  - When asymmetrical, elastic crystals are deformed by a force → Electrical potential will be developed
  - Reversible, i.e., if a potential is applied between the surfaces of the crystal, it will change physical dimension
- Magnitude and polarity of induced charges $\propto$ Magnitude and direction of applied force

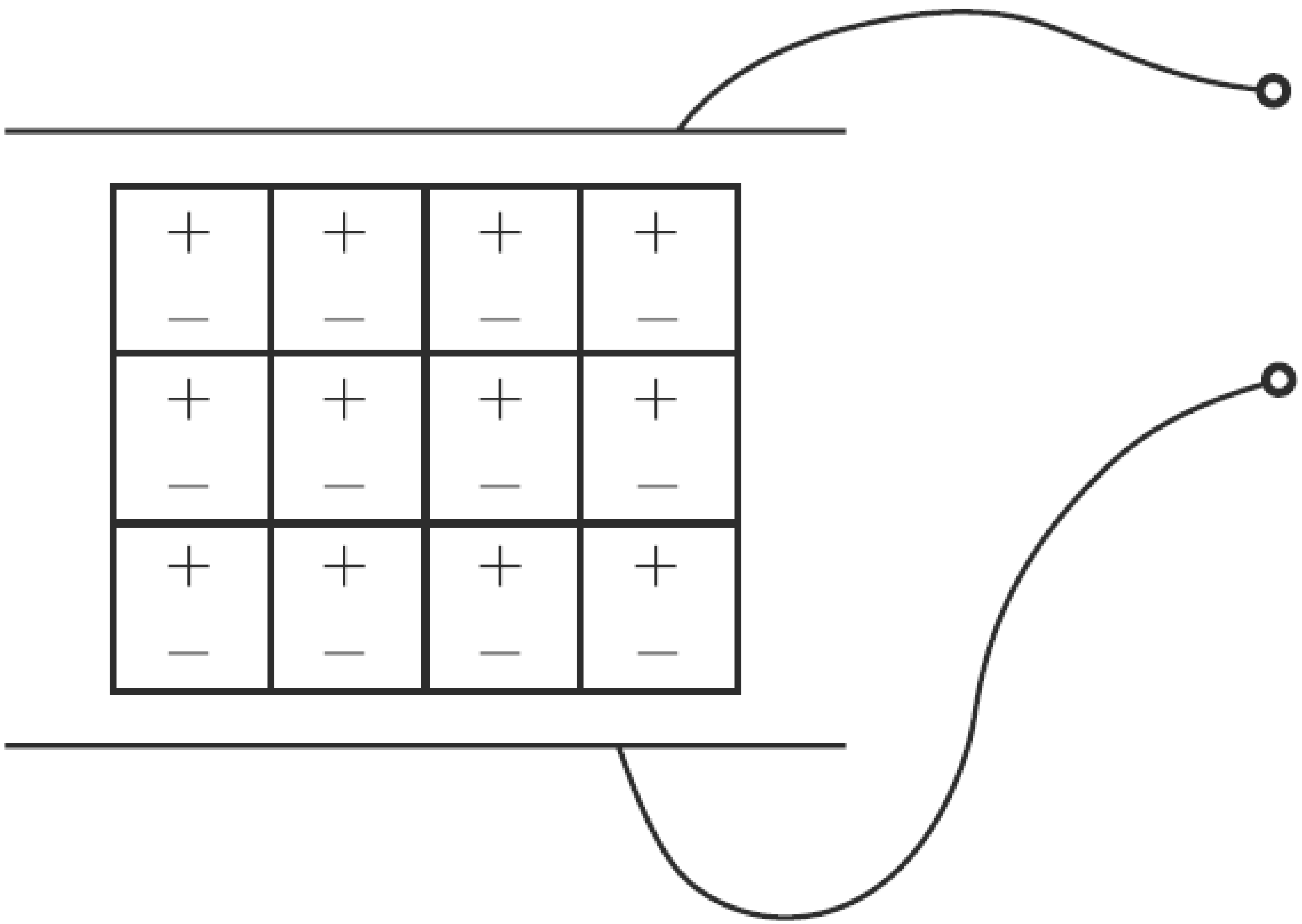


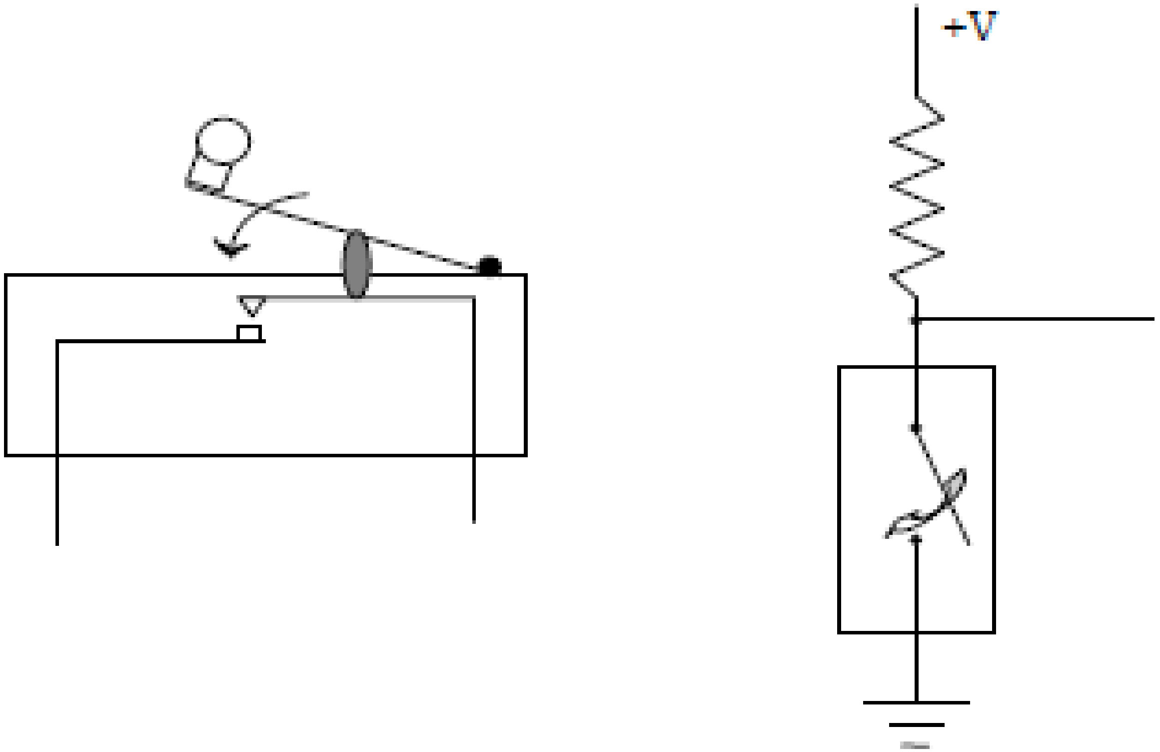
Fig. Piezoelectric sensor

Piezoelectric Sensor … / Current-based Sensing

- Materials: Quartz, Tourmaline, Rochalle salt, and others
- 1 to 20 kN
- Used for instantaneous change in force (dynamic force)
- Current-based sensing: Uses the principle of electric motor, i.e., torque $\propto$ current drawn (motor characteristics are known)

External Sensors: Contact Type *Limit Switch*

- Limit switch has on/off character.
- It has pressure sensitive mechanical arm.
- Can be normally open (NO) or normally close (NC)
- Limitations
  - Mechanical failure occurs
  - Mean time between failure is low.
  - Speed of operation is slow.

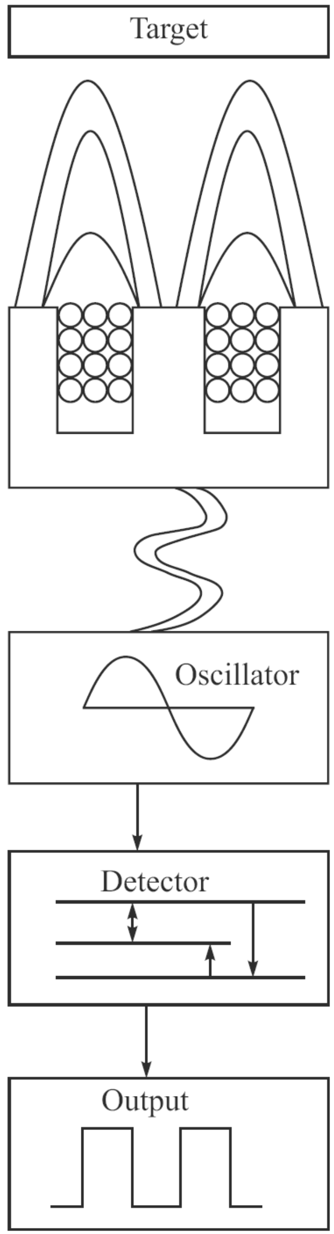


(a) (b)

Fig. Limit switch

External Sensors: Non Contact Type *Proximity Sensor (PS)*

- Detects the presence and absence of an object.
- Inductive PS: used for sensing metallic objects.
- Capacitive PS: used for sensing metallic and other objects as well.



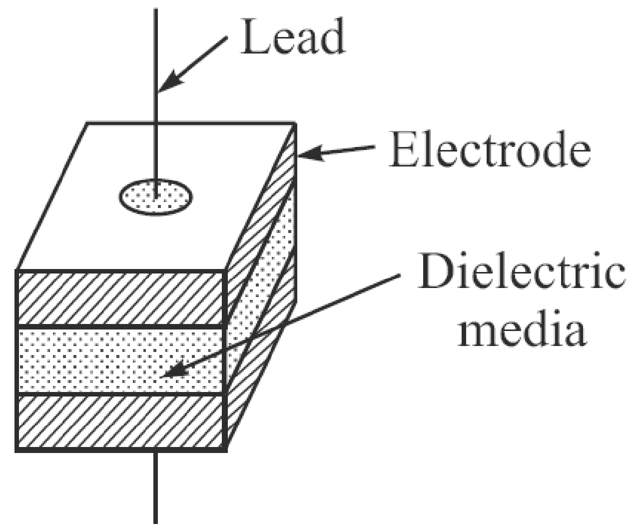


Fig. Principle of capacitive sensors

Vision: *Computer Vision or Machine Vision or Robot Vision*

- Used for extracting information about the external world from light rays imaged by a camera or an eye.
- Task of vision systems used with robotics
  - Inspection
  - Identification
  - Visual servoing and navigation control

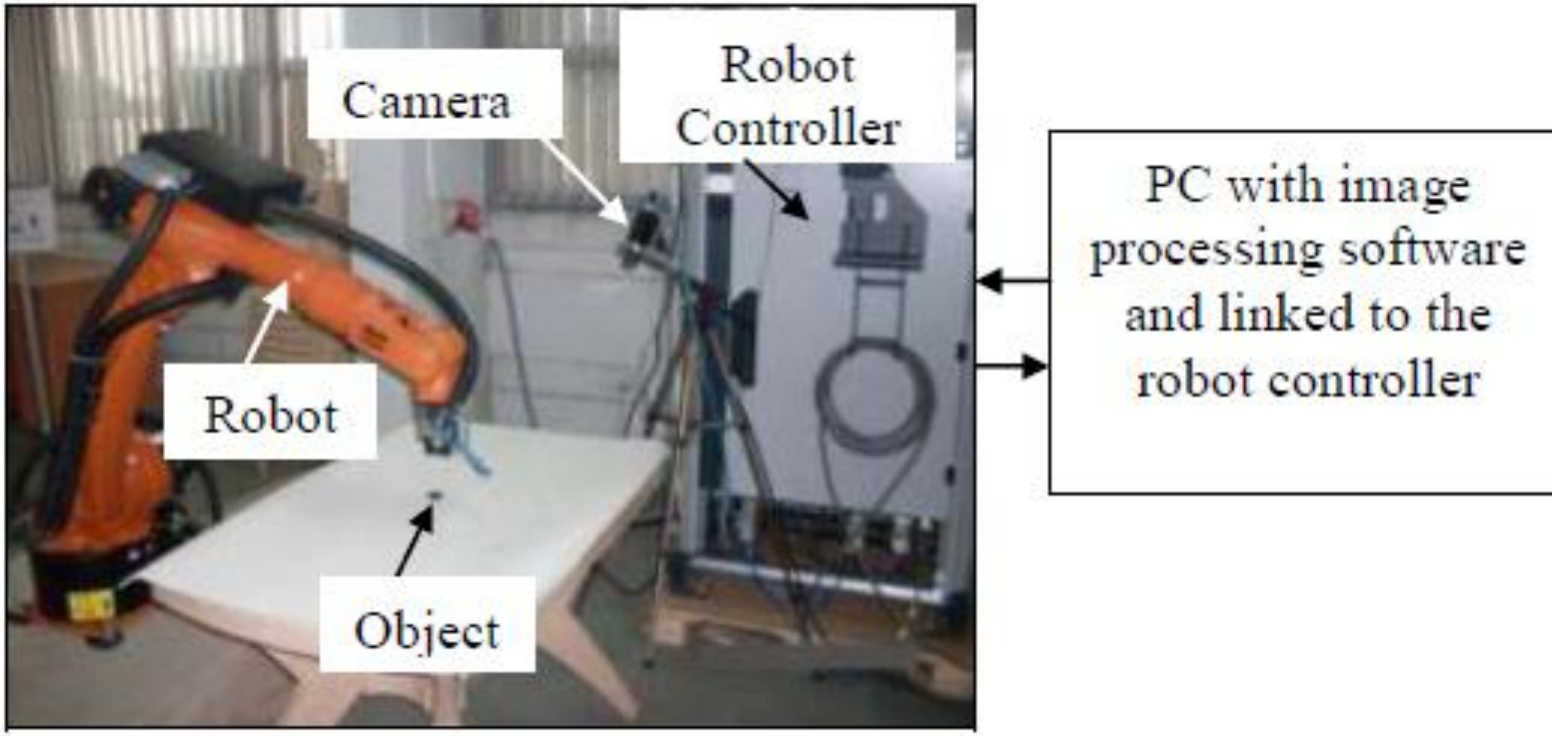
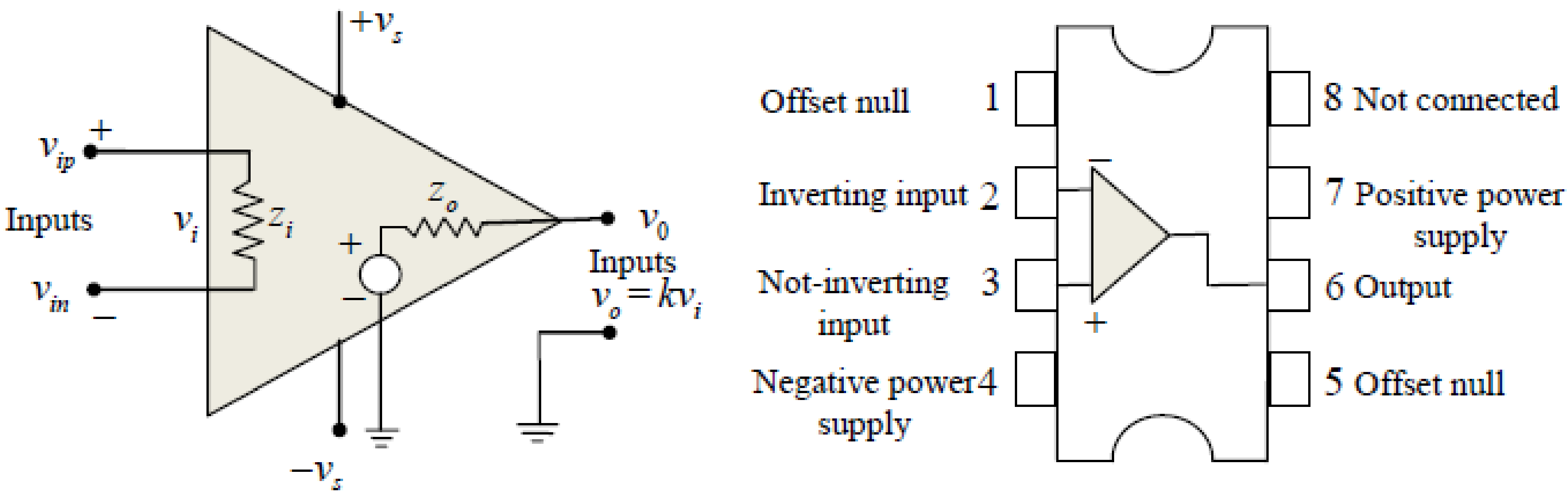


Fig. Hardware components of a vision system
[Courtesy: PAR Lab., IIT Delhi]

Signal Conditioning

- Data acquired by sensors require conditioning or processing to use it quantitatively
- Commonly used devices used for signal conditioning
  - Amplifiers: Op-amp are most widely used



(a) Schematic model

(b) A 8-pin dual in-line package

Fig. Operational amplifier

Sensor Selection

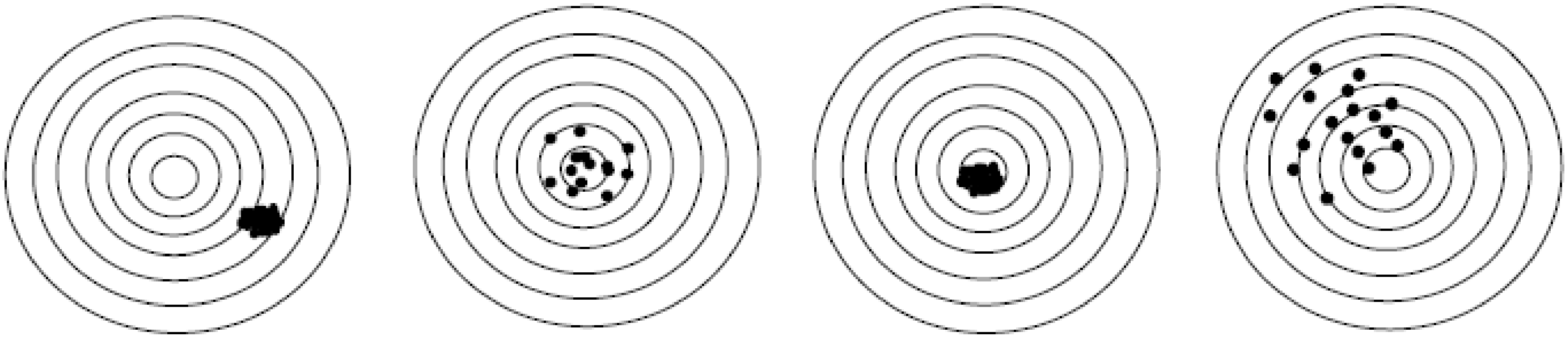
- Range
  - Difference of output and input
- Sensitivity
  - Ratio of the change of output to change in input
- Linearity
  - Linearity is a measure of the constancy of the ratio of output to input

Sensor Selection …

- Linearity
  – Constancy of ratio of output to input
- Response time
  – Time required for a change in input to be observable as a stable change in output
  – For initially oscillating signals, settled value is considered
- Bandwidth

Sensor Selection …

- Accuracy
  – Measure of difference between measurement and actual values
- Repeatability and Precision
  – Measure of the difference in value between two successive measurements under the same conditions, and is a far less stringent criterion than accuracy



(a) Poor Accuracy
Good precision

(b) Good Accuracy
Poor precision

(c) Good Accuracy
Good precision

(d) Poor Accuracy
Poor precision

Fig. Interpretation of accuracy and precision

Sensor Selection …

- Resolution and Threshold
  - measure of the number of measurement within a range from minimum to
- Hysteresis
  - change in the input/output curve when the direction of motion changes, as indicated

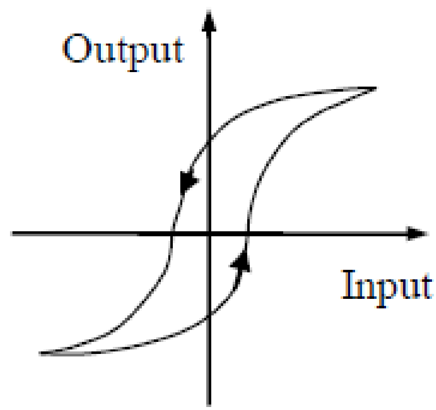


Fig. Hysteresis

Sensor Selection …

- Type of output
  - Mechanical movement, an electrical current or voltage, a pressure, or liquid level, a light intensity, or another form
- Some more consideration which sensor selection
  - Size and Weight, Environmental Conditions
  - Reliability and Maintainability, Interfacing

Summary

- Motors are explained
- How to choose a motor was explained
- Sensors were presented

Robot Design

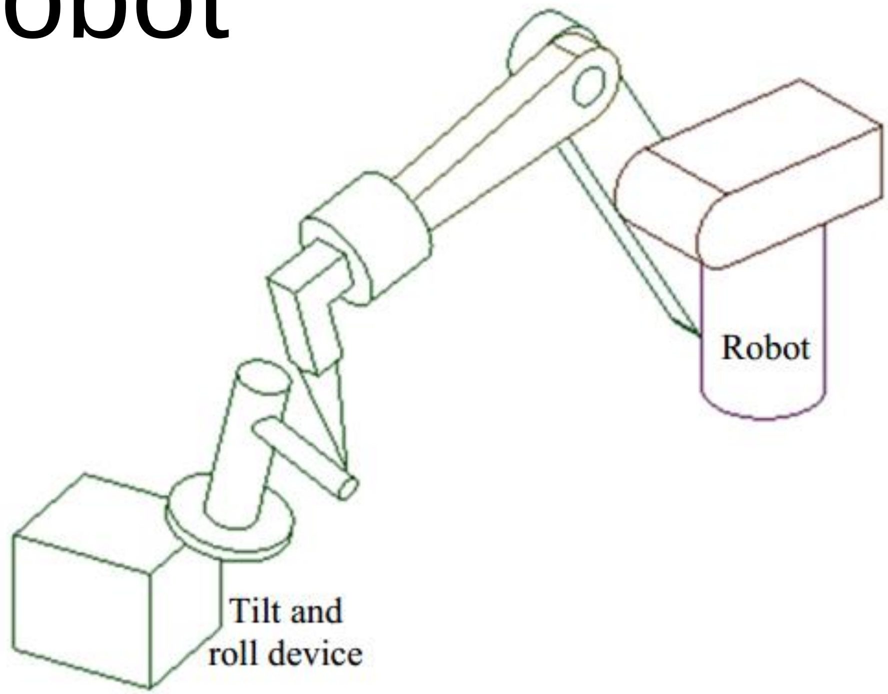
Prof. S.K. Saha
Department of Mechanical Engineering
IIT Delhi

Outline

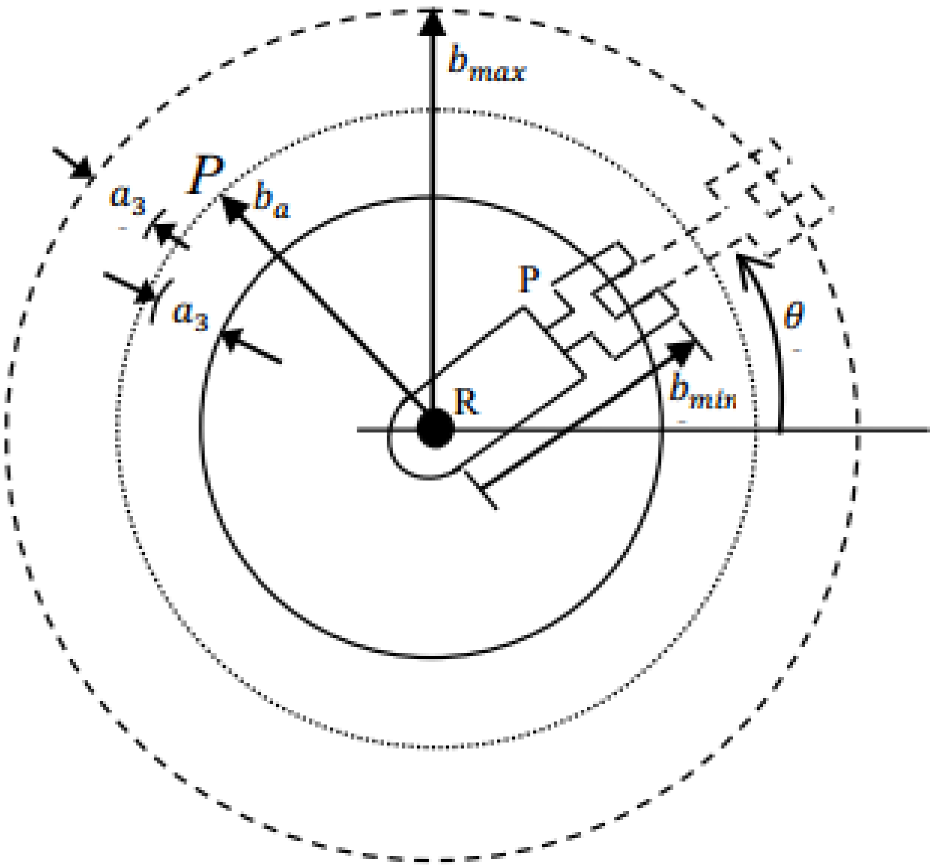
- Kinematic criteria
  - Workspace
  - Singularity
  - Dexterity and Manipulability
- Kinetostatic criterion
- Structural aspects
- Actuator and Drive selections
- Dynamic and Control criterion

Functional Requirements of a Robot

- Payload
- Mobility
- Configuration



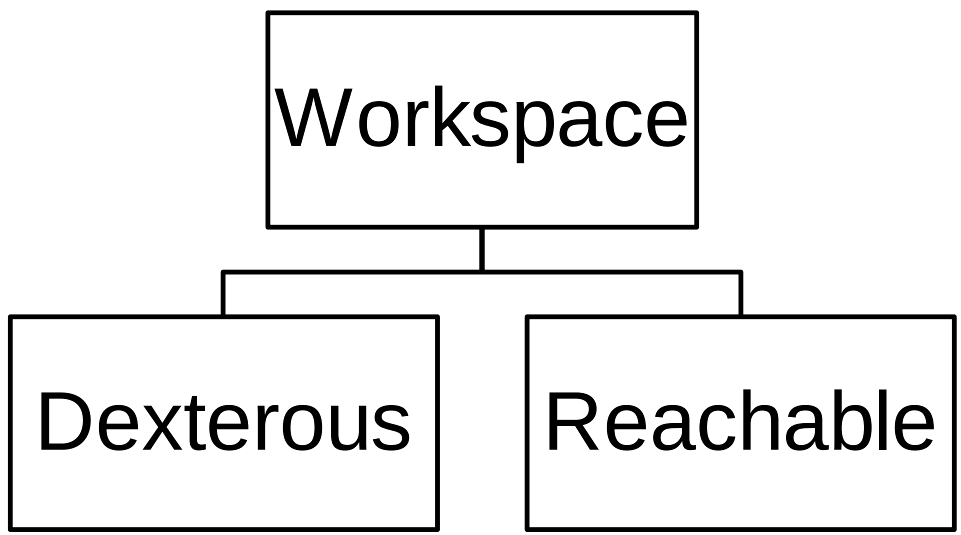
- Speed, Accuracy and Repeatability
- Actuators and Sensors



$$b_{\min} \le b \le b_{\max}, \text{ for } 0^o \le \theta \le 360^o$$

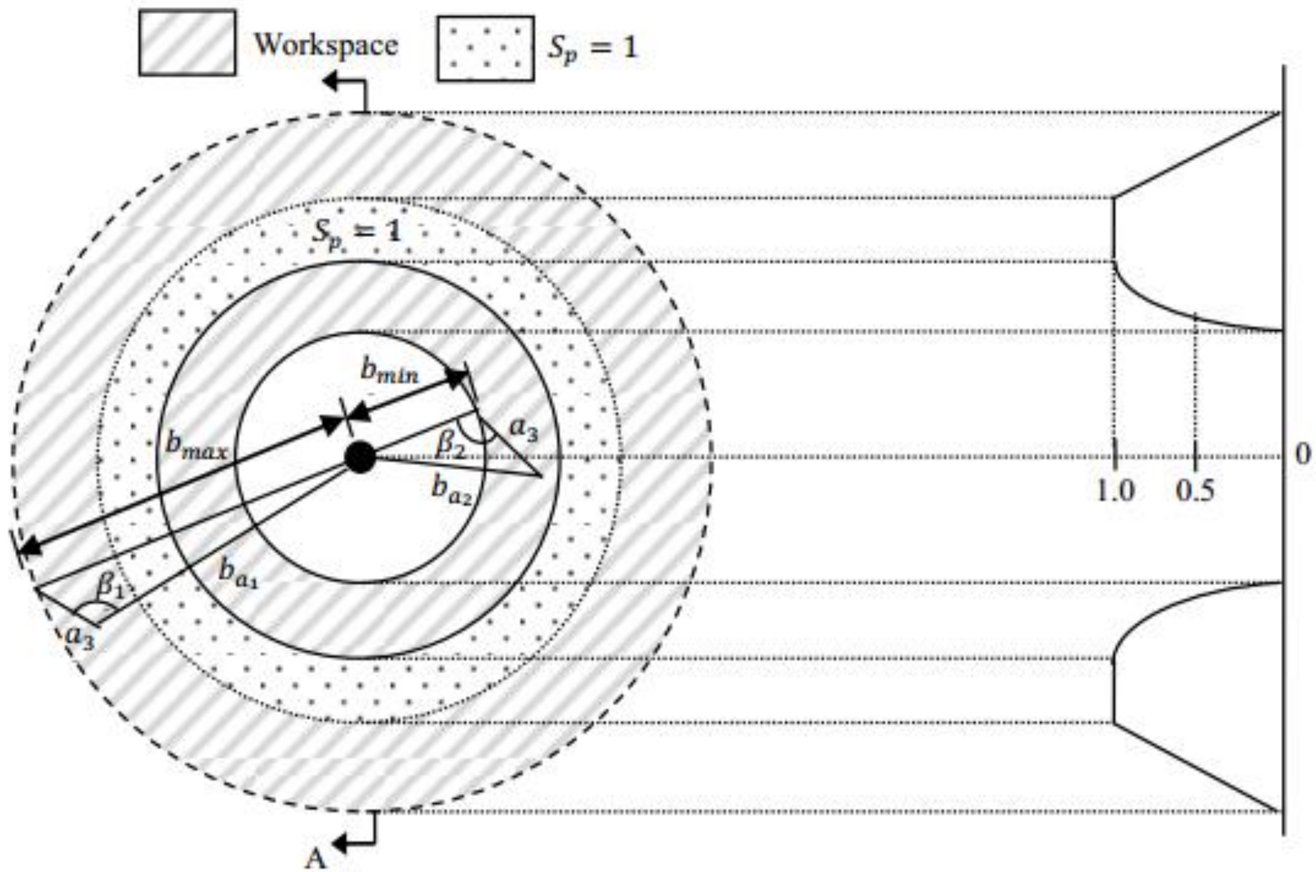
Kinematic and Kinetostatic Measures

- Workspace of a robot manipulator: Space composed of all points which can be reached by its end-effector.



All orientations of the end-effector

At least one orientation of the end-effector



(a) Workspace of RP manipulator (b) Service index S_p at A-A

Kinematic and Kinetostatic Measures

Singularity

$$\det[\mathbf{J}(\boldsymbol{\theta})] = 0$$

Workspace boundary singularities

Such singularities occur when the manipulator is fully stretched out or folded back on itself such that the end-effector is near or at the boundary of the workspace

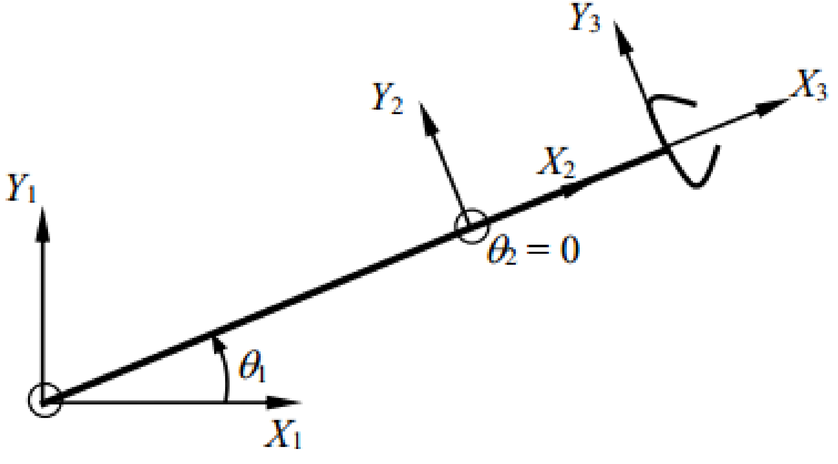
Workspace interior singularities

Such singularities occur away from the workspace boundary and generally are caused by two or more joint axes lining up

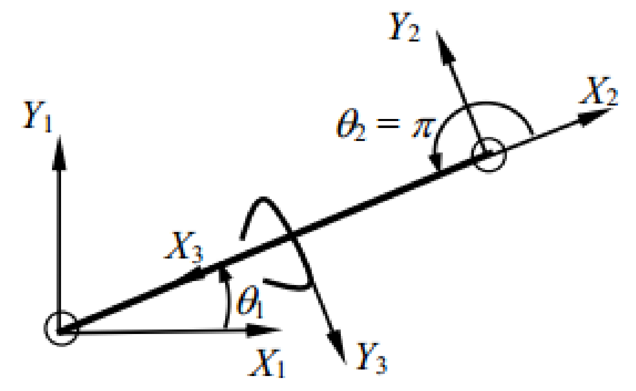
Example: Singularity of 2-link RR Arm

$$\mathbf{J} \equiv \begin{bmatrix} -a_1 s_1 - a_2 s_{12} & -a_2 s_{12} \\ a_1 c_1 + a_2 c_{12} & a_2 c_{12} \end{bmatrix}$$

$$\theta_2 = 0 \text{ or } \pi$$



(a) Stretched



(b) Folded

Dexterity and Manipulability

- Dexterity → $w_d = \det(\mathbf{J})$
- Manipulability → $w_m = \sqrt{\det(\mathbf{J}\mathbf{J}^T)}$
- Non-redundant manipulator → square Jacobian

$$w_m = \left|\det(\mathbf{J})\right| \qquad w_d = w_m$$

Velocity Ellipsoid

- Transformation characteristics of the joint rates required to produce a unity end-effector velocity in all possible directions , i.e.,

$$\mathbf{t}_e^T \mathbf{t}_e = 1$$

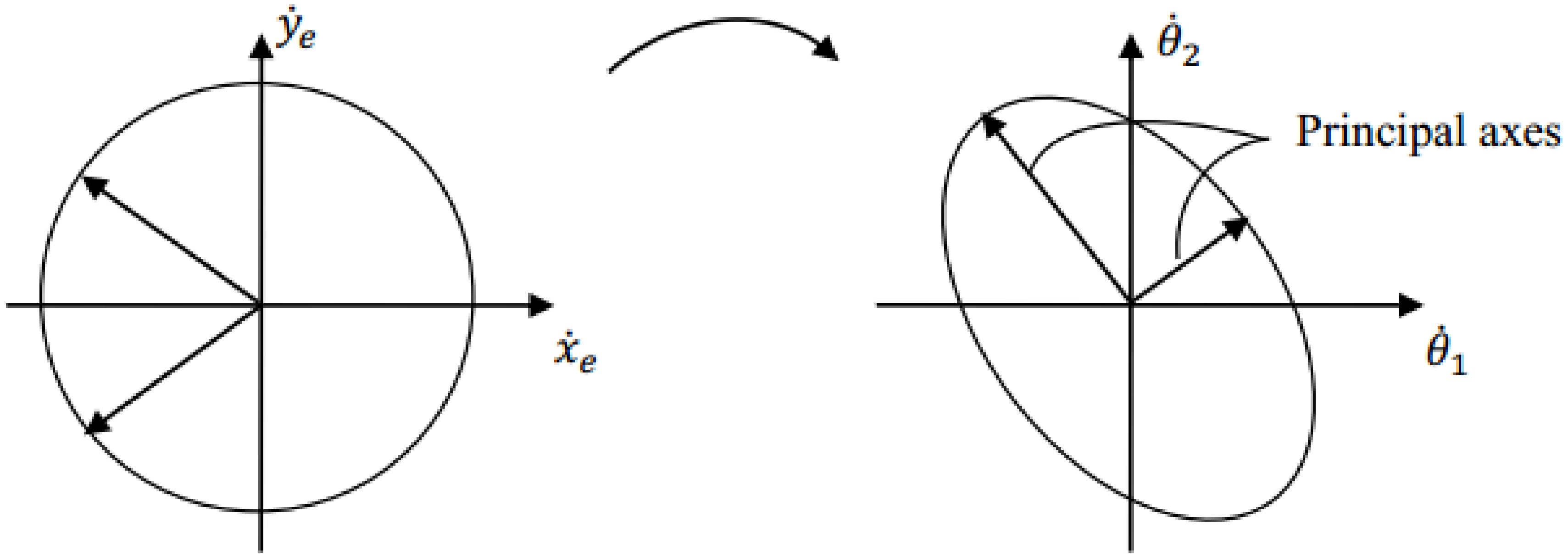
$$\dot{\boldsymbol{\theta}}^T \mathbf{J}^T \mathbf{J} \dot{\boldsymbol{\theta}} = 1$$

Ellipsoid in *n*-dimensional joint space

Velocity Ellipsoid

- Shape and orientation of ellipsoid changes
- If det(**J**) $\cong$ 1, ellipsoid is sphere (desired)
  - Better transmission characteristics
  - Called isotropic configuration
- If det(**J**) $\cong$ 0, ellipsoid is a cylinder (dangerous)
  - Mechanical advantage $\cong \propto$
  - Called singular configuration

Velocity Ellipsoid of a 2-DOF Arm



(a) End-effector space (circle)   (b) Joint space (ellipse)

Force Ellipsoid

- Characteristics/quality of force transmission by a robot arm can be given by the comparison of the end-effector force/torque (wrench) produced by a unit magnitude of joint torques, i.e.,

$$\boldsymbol{\tau}^{\mathrm{T}}\boldsymbol{\tau} = 1 \quad \Rightarrow \quad \mathbf{w}_e^T \mathbf{J}\mathbf{J}^T \mathbf{w}_e = 1$$

Equation of an ellipsoid

(ellipse for a 2-link 2-DOF arm)

Force Ellipsoid

- Shape of ellipse (2-link arm) changes
- If det(**J**) $\cong$ 1, ellipse is circle (desired)
  - Better transmission characteristics
  - Called isotropic configuration
- If det(**J**) $\cong$ 0, ellipse is a line (dangerous)
  - Mechanical advantage $\cong \propto$
  - Called singular configuration

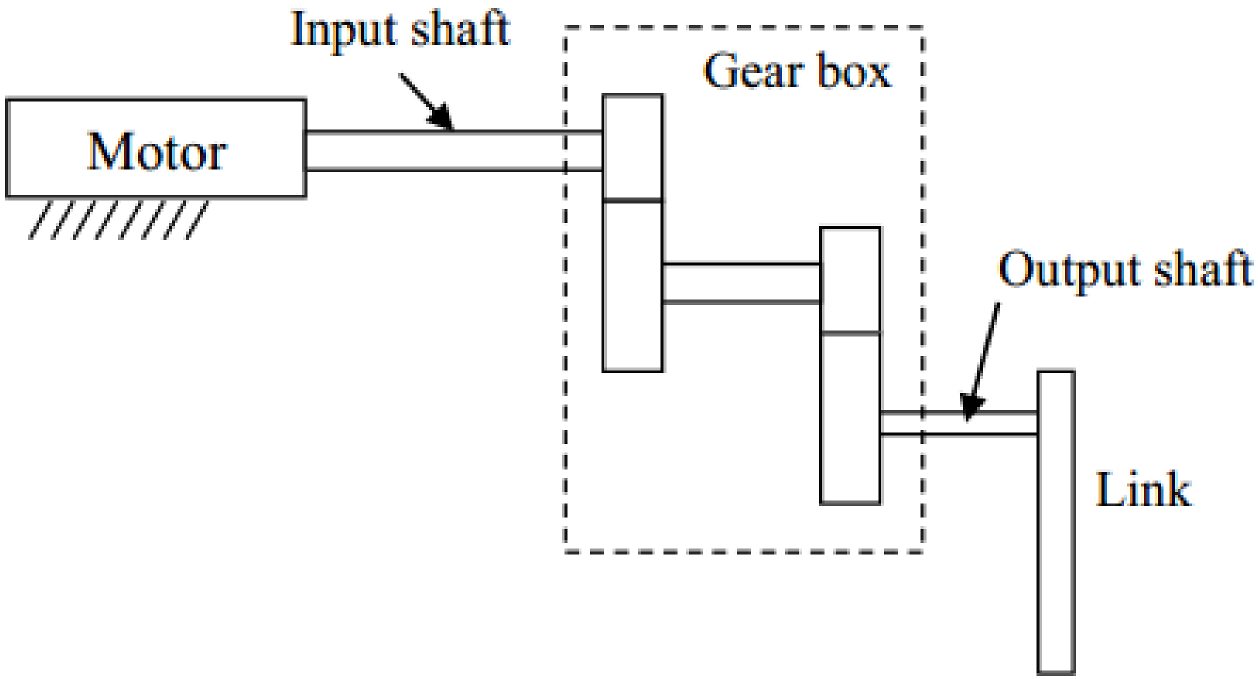
Structural: Link Material

- Mild (low carbon) steel:

  S_y = 350 Mpa; S_u = 420 Mpa
- High alloyed steel

  S_y = 1750-1900 Mpa; S_u = 2000-2300 Mpa
- Aluminum
- S_y = 150-500 Mpa; S_u = 165-580 Mpa

Manipulator Stiffness



$$\frac{1}{k_e} = \frac{1}{\eta^2 k_1} + \frac{1}{k_2}$$

$k_e \equiv$ equivalent stiffness

$\eta \equiv$ gear ratio

Motor Selection

- For robot applications
  - Positioning accuracy, reliability, speed of operation, cost, etc.
- Electric is clean + Capable of high precision
- Electronics is cheap but more heat
- Pneumatics are not for high precision for continuous path

Motor Selection (contd.)

- Hydraulics can generate more power in compact volume
- Capable of high torque + Rapid operations
- Power for electro-hydraulic valve is small but expensive
- All power can be from one powerful hydraulic pump located at distance

Thumb Rule for Motor Selection

- Rapid movement with high torques (> 3.5 kW): Hydraulic actuator
- < 1.5 kW (no fire hazard): Electric motors
- 1-5 kW: Availability or cost will determine the choice

Sample Calculations

Example: Selection of a Motor

Two meter robot arm to lift 25 kg mass at 10 rpm

- Force = 25 x 9.81 = 245.25 N
- Torque = 245.25 x 2 = 490.5 Nm
- Speed = 2π x 10/60 = 1.047 rad/sec
- Power = Torque x Speed = 0.513 kW
- Simple but sufficient for approximation

Simple Calculation

2 m robot arm to lift 25 kg mass at 10 rpm

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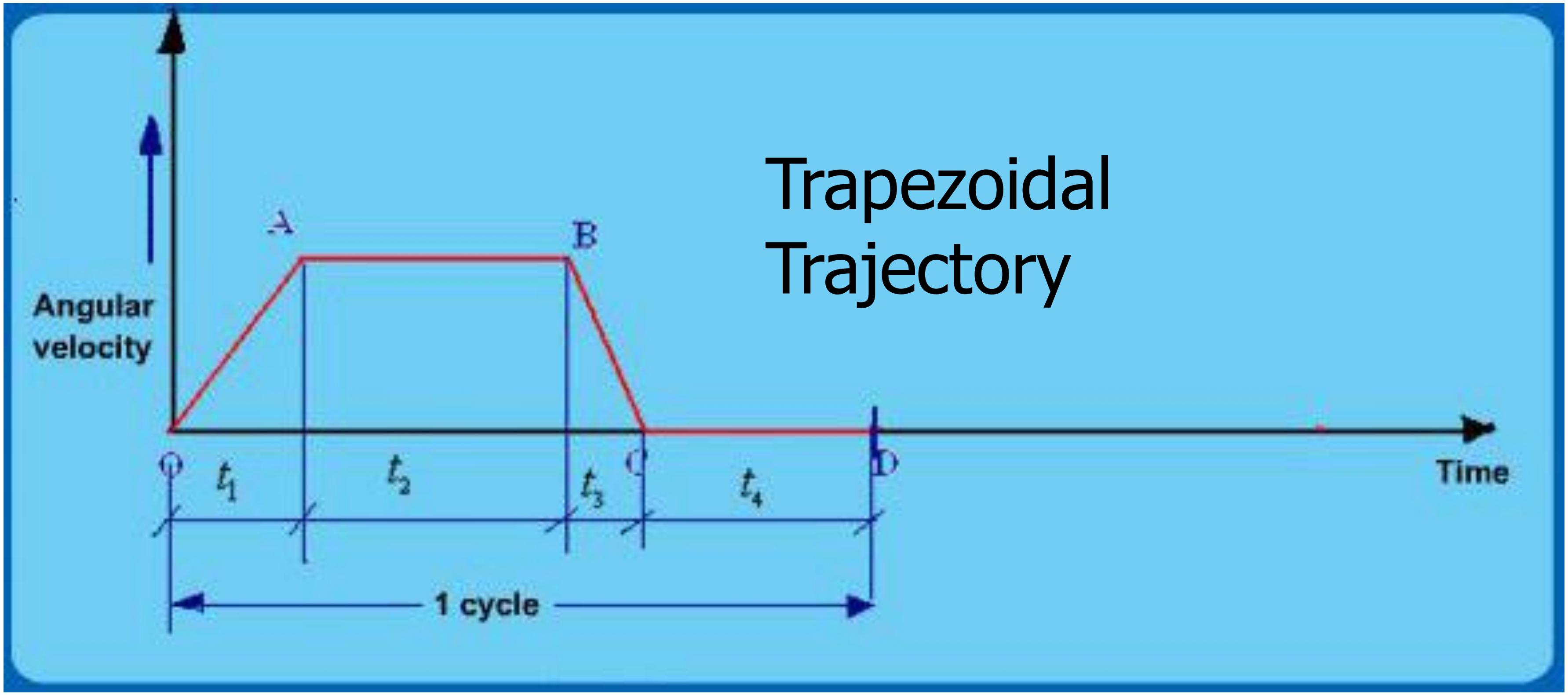
Practical Application



Subscript l for load; m for motor;

$G = \omega_l / \omega_m$ (< 1); η: Motor + Gear box efficiency

Accelerations & Torques

Ang. accn. during t_1: $$\alpha_1 = \frac{\omega_a - o}{t_1}$$

Ang. accn. during t_2: Zero (Const. Vel.)

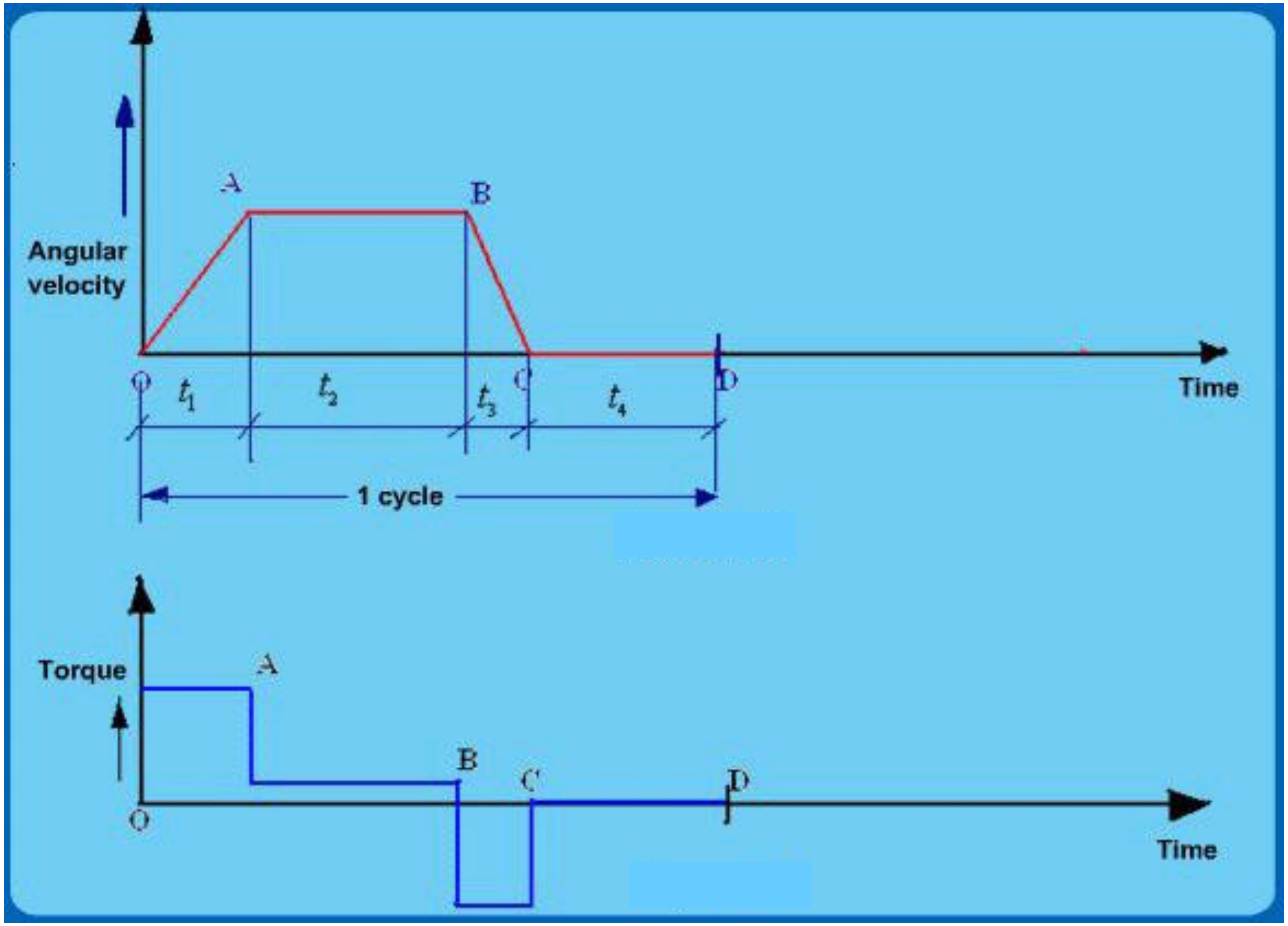
Ang. accn. during t_3: $$\alpha_3 = \frac{\omega_b - 0}{t_3}$$

Torque during t_1: $T_1 =$ $$(I_m + \frac{G^2}{\eta} I_l)\alpha_1 + T_f \frac{G}{\eta}$$

Torque during t_2: $T_2 =$ $$T_f \frac{G}{\eta}$$

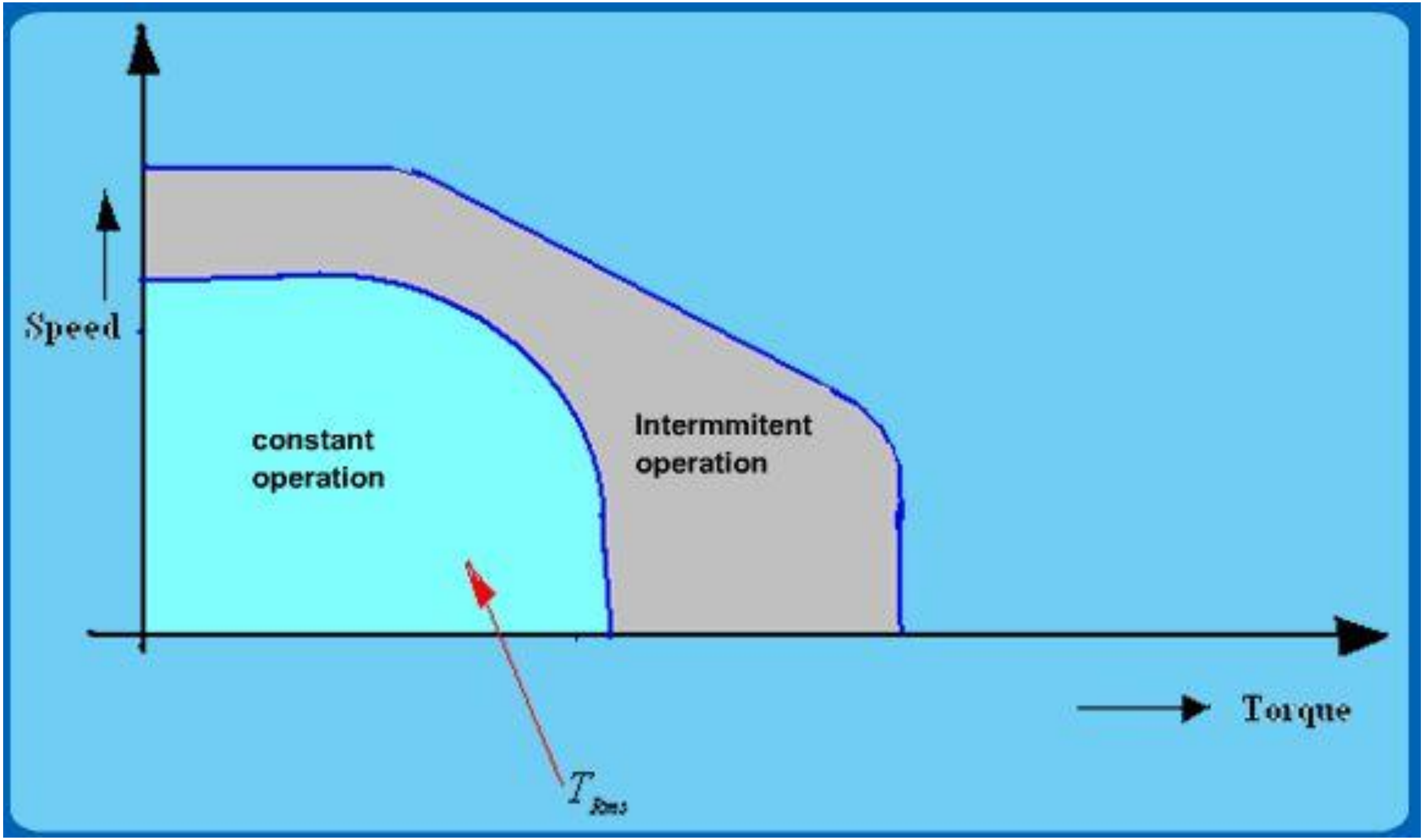
Torque during t_3: $T_3 =$ $$(I_m + \frac{G^2}{\eta} I_l)\alpha_3 - T_f \frac{G}{\eta}$$

RMS Value



$$T_{Rms} = \sqrt{\frac{(T_1^2 \times t_1) + (T_2^2 \times t_2) + (T_3^2 \times t_3) + (zero)t_4}{t_1 + t_2 + t_3 + t_4}}$$

Motor Performance



Final Selection

- Peak speed and peak torque requirements , where T_{Peak} is max of (magnitudes) T_1, T_2, and T_3
- Use individual torque and RMS values + Performance curves provided by the manufacturer.
- Check heat generation + natural frequency of the drive.

Driver Selection

- Driver of a DC motor: A hardware unit which generates the necessary current to energize the windings of the motor
- Commercial motors come with matching drive systems

Dynamics and Control Measures

- Rule of Thumb

$$\omega_n \le \frac{1}{2}\omega_r$$

ω_n : closed-loop natural frequency

ω_r : lowest structural resonant frequency

Summary

- Kinematics and kinetostatic criteria
- Structural aspects
- Motor selection
- Dynamics and control point of view

Thank you!

<u>For any doubts, contact</u>

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