SKN3022
PROCESS INSTRUMENTATION
CHAPTER VII

FINAL CONTROL ELEMENT

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FINAL CONTROL ELEMENT (FCE)

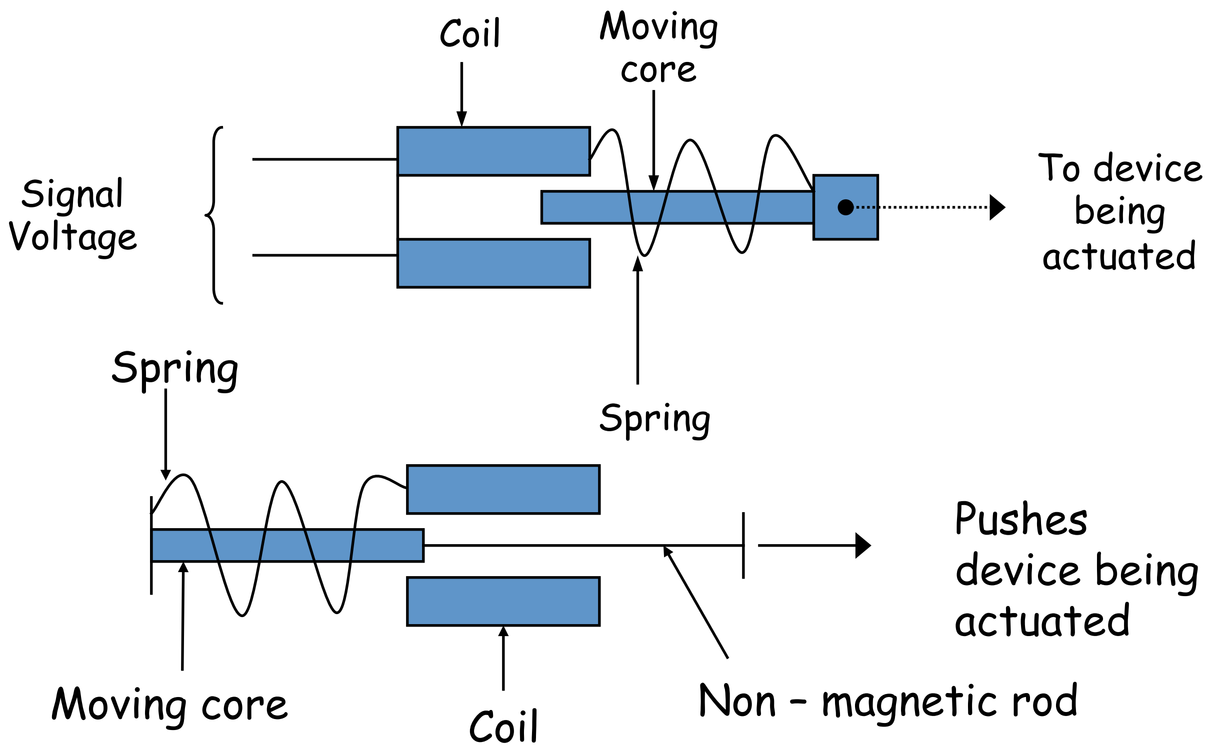
- **Carries out control actions through control mechanism produced by actuators.**
- **The FCE commonly used in industries are valves.**

I. ACTUATOR

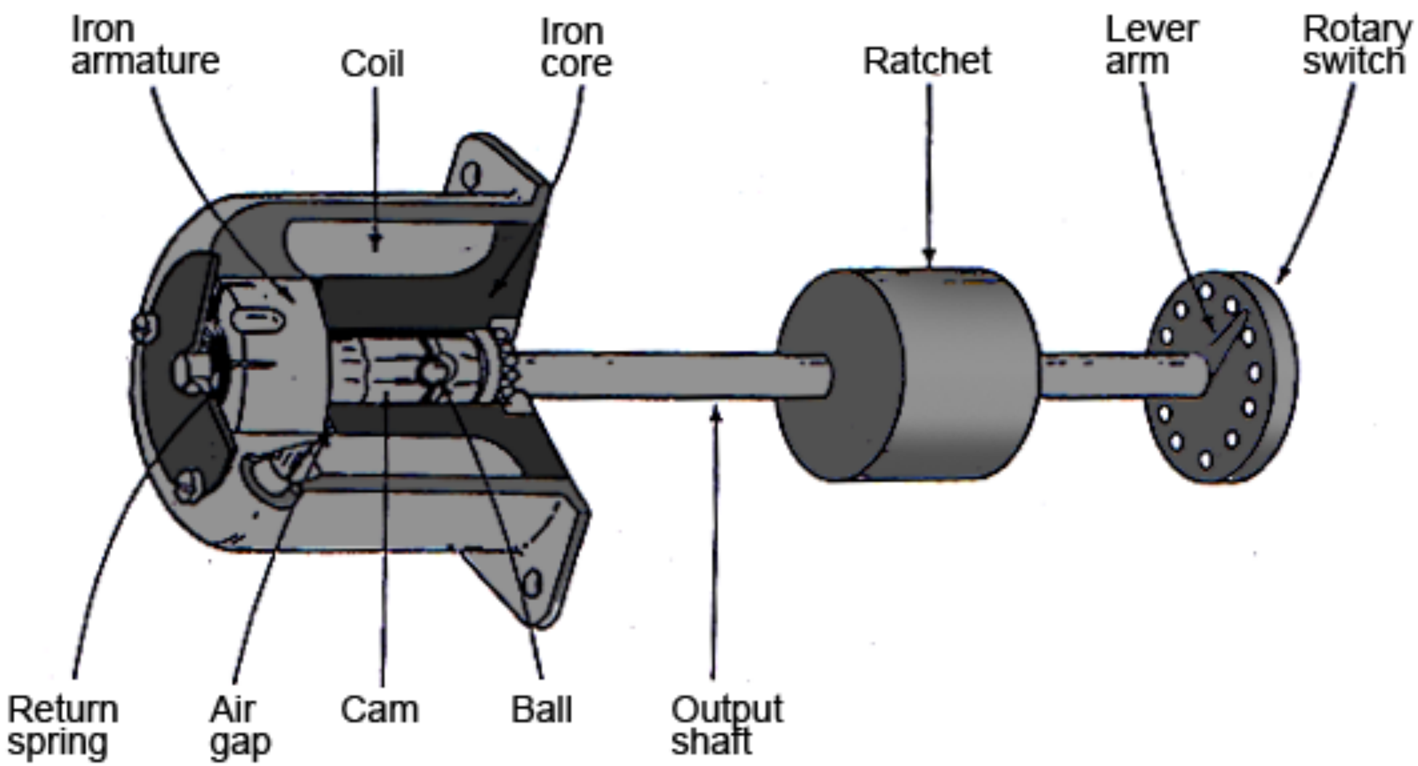
- **A peripheral which converts control signals from the controller to the moving part (mechanically) of the final control element.**
- **Two types of actuators used in control systems are solenoid and motor.**

1. Solenoid

- There are two working principles of a solenoid system either are as a pusher and a puller.
- The elements in a solenoid consists of a coil, core and a spring. When the coil is energized from the control signal, the magnetic field around the coil will pull the core towards the coil and vice versa when the coil is de-energized.
- The peripheral that needs to be moved like the valve will be connected to the edge of the core and will move with it. Therefore, the valve will be opened or closed according to the movement of the solenoid.
- This solenoid is known as a linear actuator and is used to push and pull a horizontal object.
- For a non linear movement, a rotary solenoid is used.



Linear Solenoid Operation



Rotary Solenoid Operation

Basic Structure of a Solenoid

- Solenoid is an electromagnetic equipment which has a moving core.
- This moving core is known as a "plunger".
- The movement of the core depends on the electromagnetic field and the spring force.
- Basically, solenoid consists of wire coil which circles the non magnetic coil form.

Un-energized State

- Plunger will be at original position

Energized state

- When currents flows through the coil, an electromagnetic field will be produced at both ends of the core. “South-pole” (stationary core) will pull the “north-pole” (moving core) and this will cause the core to move inwards. This condition will go on until the electricity supply is stopped.

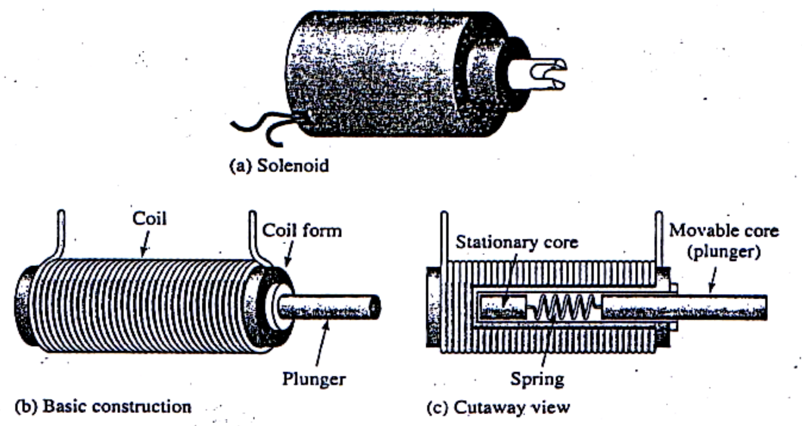
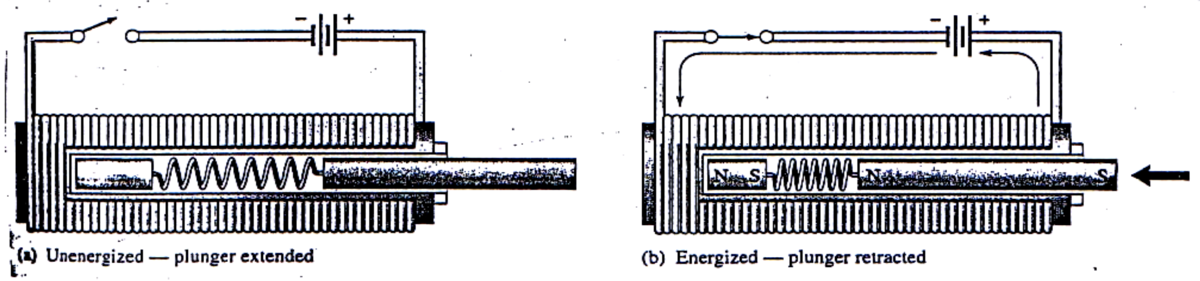


FIGURE 7–16
Basic solenoid structure.



Basic Solenoid Operation

2. Motor/Generator

BASIC OPERATION OF A DC MOTOR

- Most machines operate based on the interaction between conductor and electromagnetic field.
- Example of an electrical machine is a motor and generator.
- The operation of a generator is based on Faraday's Law where the voltage will be induced when the conductor passes through magnet flux.

2. Motor

- **Motor is needed to operate pumps, fans, compressors and others.**
- **Two types: direct current (DC) motor and alternate current (AC) motor.**

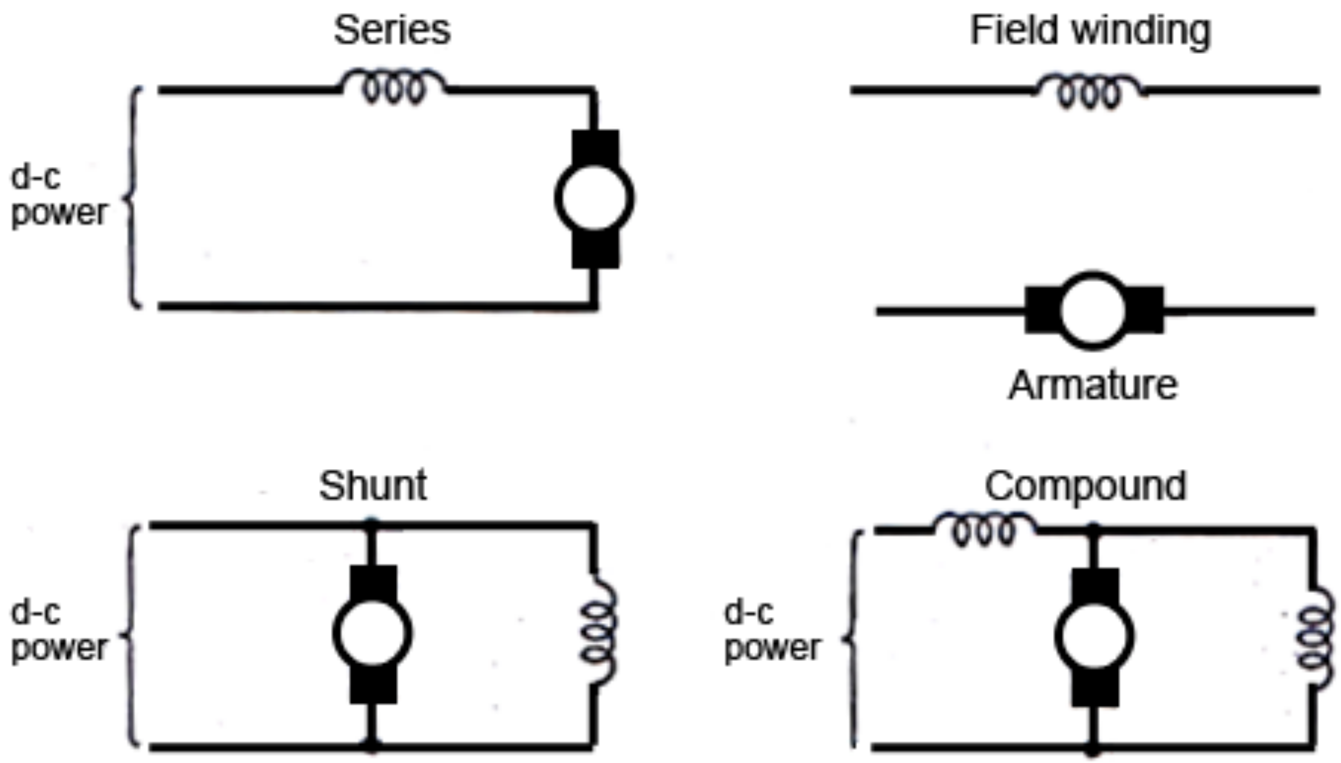
a. DC Motor

***Three types: series, shunt and compound*.**

1. **Series – has a high starting torque to overcome inertia of heavy load.**
2. **Shunt – used when steady speed is required.**
3. **Compound – combination of serial and shunt characteristics and has the capabilities to retain a steady speed using different loads and capable of producing a large torque.**

b. AC Motor

- Consists of two parts : stator and rotor.
- Functions based on the magnetic field rotation principal and can operate with single phase or poly phase AC power.



Classes of DC Motors

- **The operation of a motor is opposite than the operation of a generator because a motor only operates when voltage is supplied.**

Generator : Voltage (emf) = $\beta l u$

Motor : force = $\beta l i$

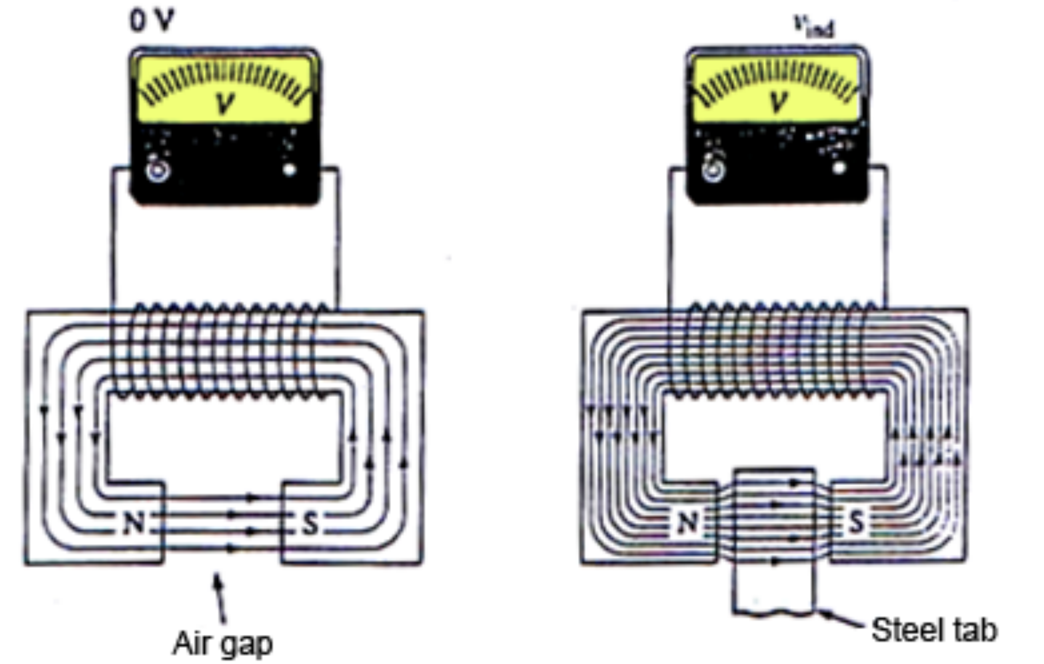
where β : *magnetic field*

l : *length of conductor*

u : *velocity*, i : *current*

i. ***Brush*** **: electric conductor made of carbon. Used to flow electric to electric motor commutator. It also gets voltage from the rotation part of the electric generator.**

ii. ***Commutator*** **: the conduction ring that is fixed to the armature in an electric motor. A commutator comes in contact with the current accumulative brushes.**

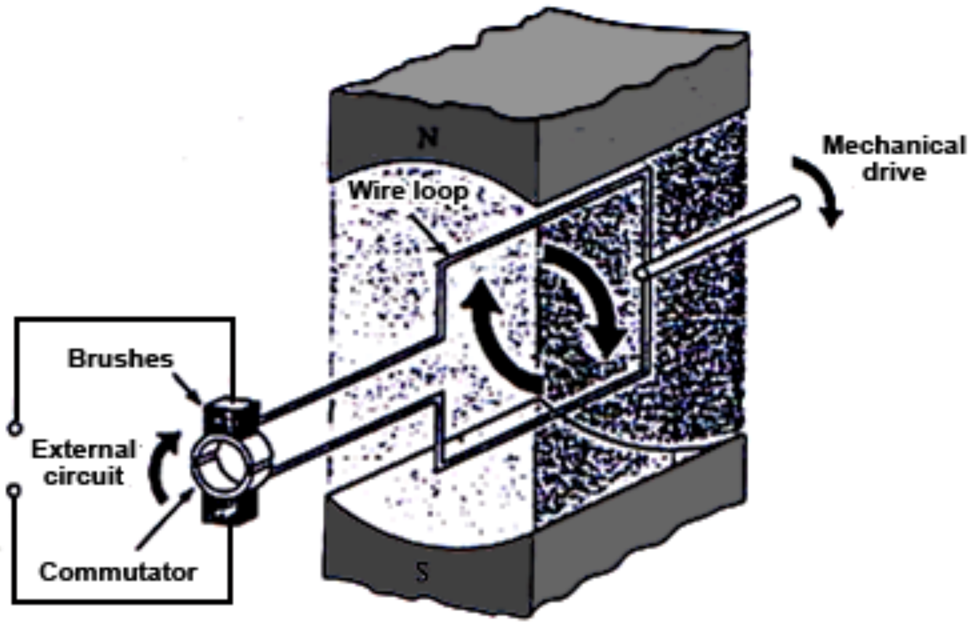


(a) There is no changing magnetic field, so there is no induced voltage

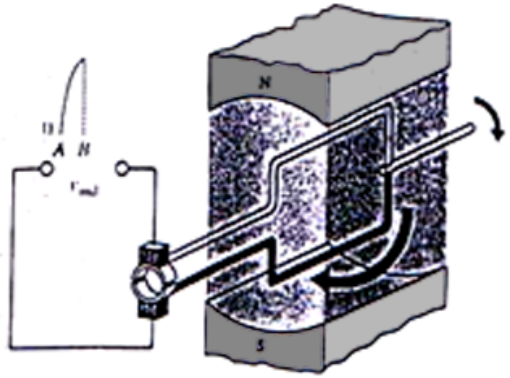
(b) Insertion of the steel tab reduces the reluctance of the air gap, causing the magnetic flux to increase and thus inducing a voltage.

As the tab passes through the air gap of the magnet, the coil senses a change in the magnetic field and a voltage is induced

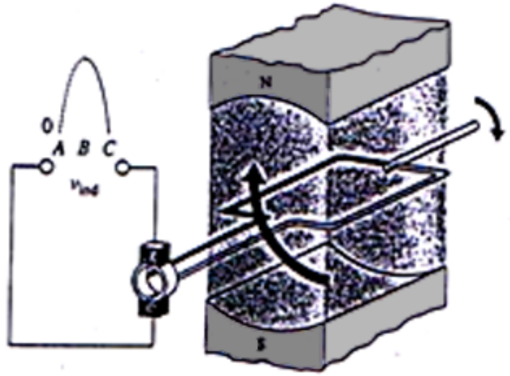
Electromagnetic Inductance Operation



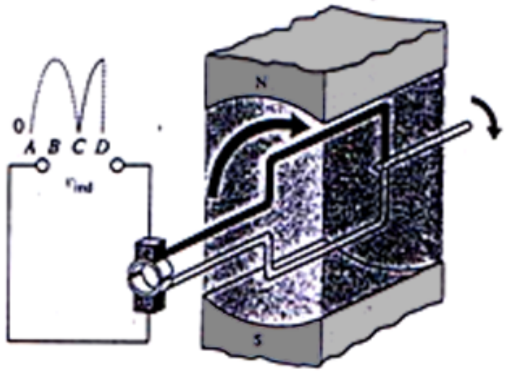
A Basic DC Generator



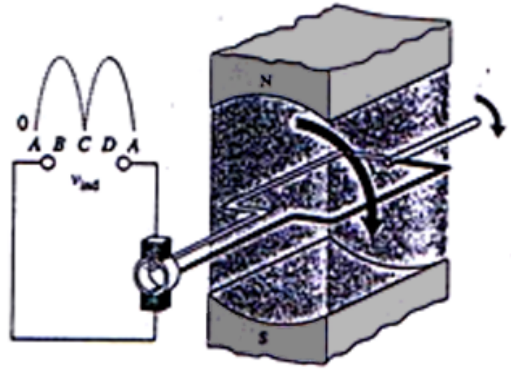
(a) Position B: Loop is moving perpendicular to flux lines, and voltage is maximum.



(b) Position C: Loop is moving parallel with flux lines, and voltage is zero.

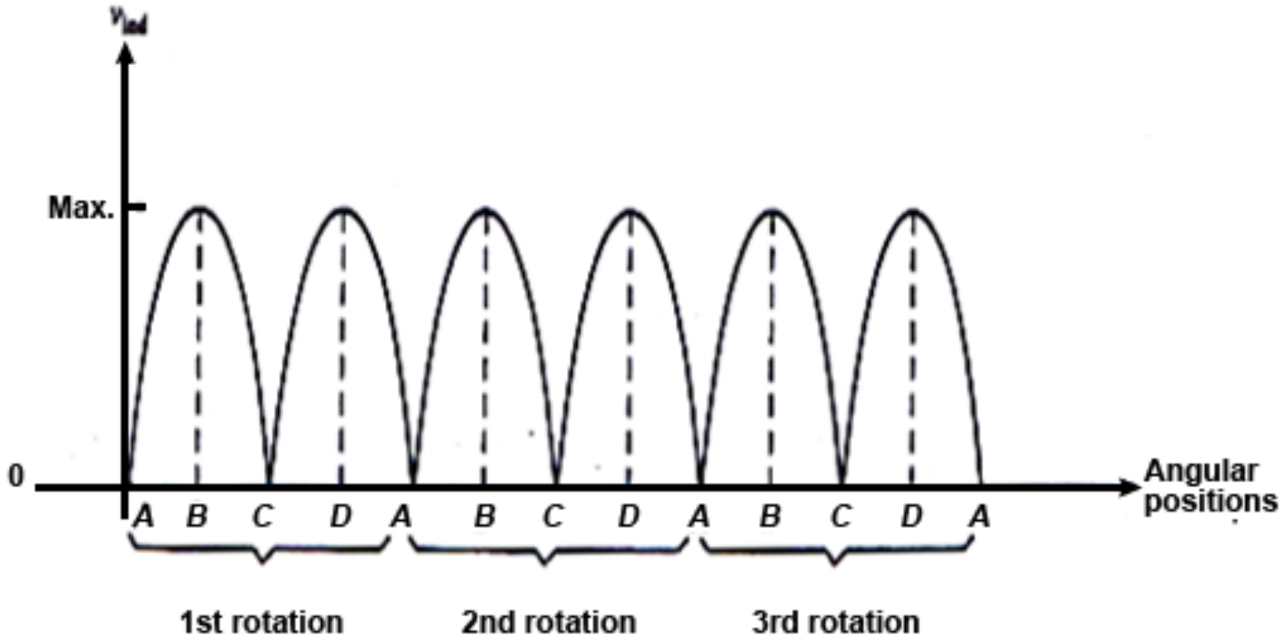


(c) Position C: Loop is moving perpendicular to flux lines, and voltage is maximum.



(d) Position A: Loop is moving parallel with flux lines, and voltage is zero.

Operation of Basic DC Generator

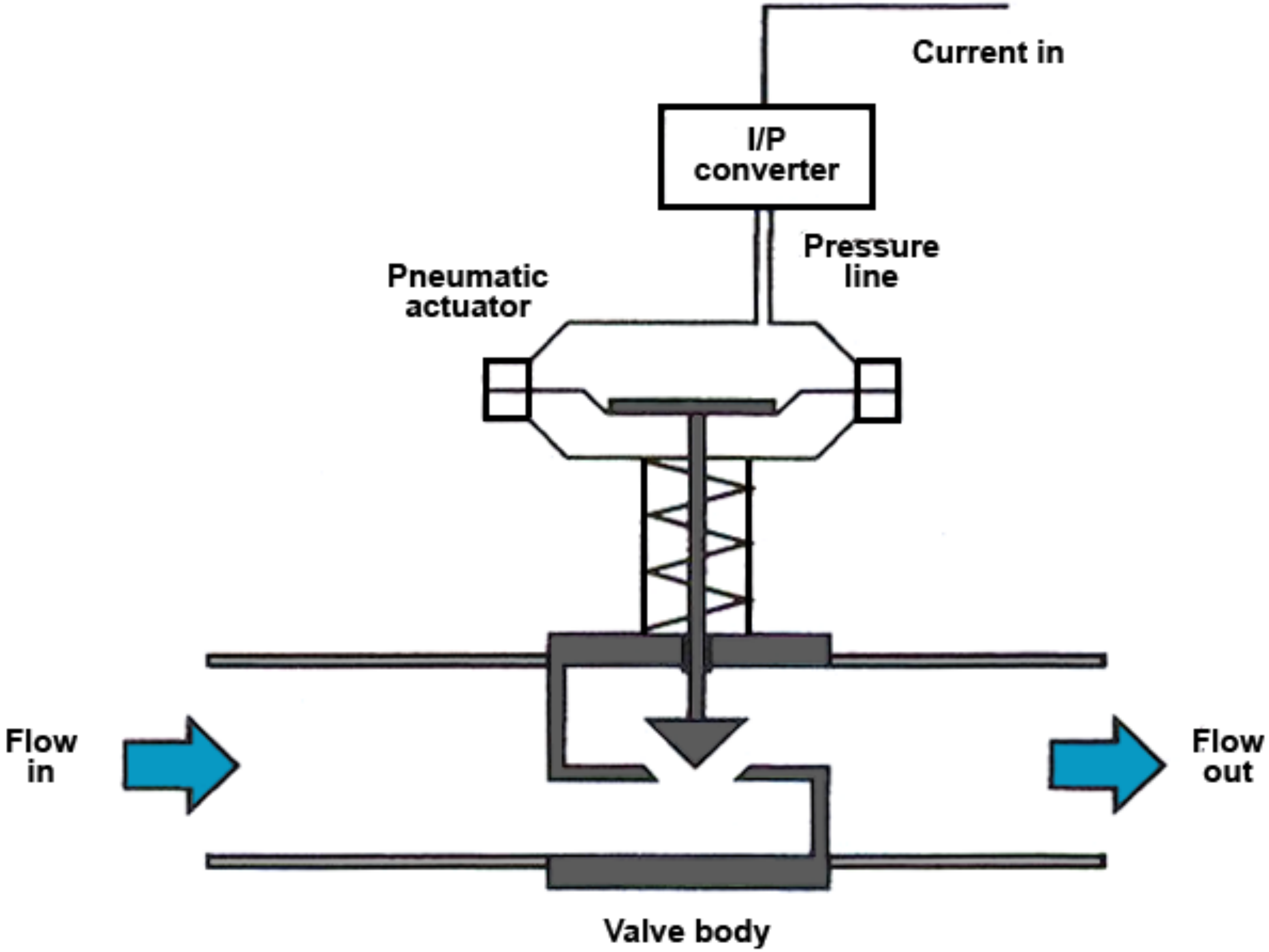


Induced Voltage Over Three Rotations of the Loop

II. CONTROL VALVES

- Various opening sizes.
- Two basic types:

1. Shut-off valve: can be fully opened or fully closed.
2. Throttling valve; the opening can be adjusted to be anywhere in between fully opened and fully closed.



A pneumatic actuator connected to a control valve. The actuator is driven by a current through an I/P converter.

III. VALVE DESIGN

- **Types:**

1. Globe Valve
2. Needle Valve
3. Ball Valve
4. Butterfly Valve

i. Globe Valve

- Mostly employed in industry.
- Consists of 3 categories:

a. Single Port

- Simple construction.
- For sizes under 2 inches.
- Has a tight valve closing.
- High imbalance of force.

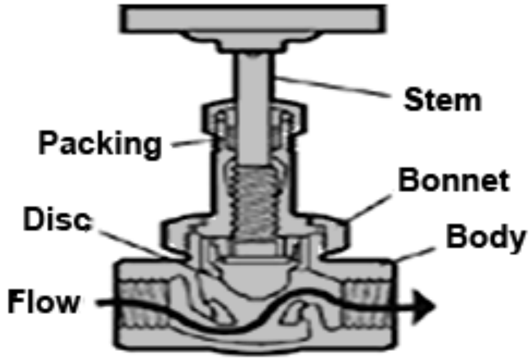
i. Globe Valve

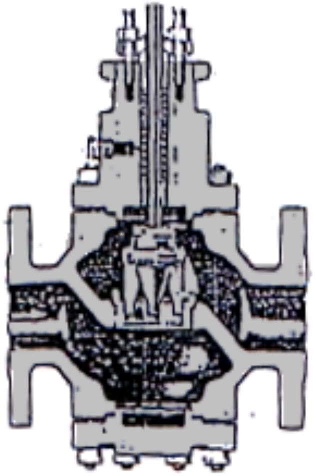
b. Double port

- Higher flow capacity (>2 inches).
- Balanced force.

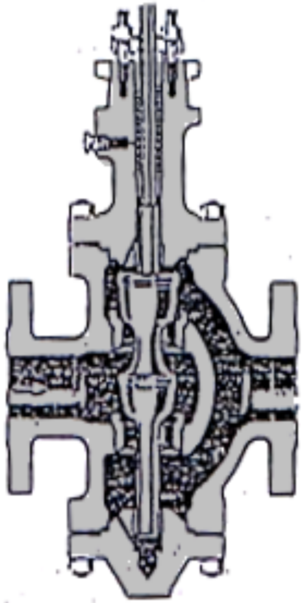
c. Three way

- To connect or divert the passage of flow.

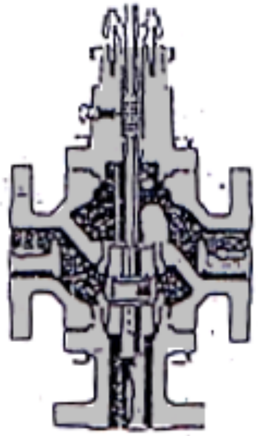




Single Port



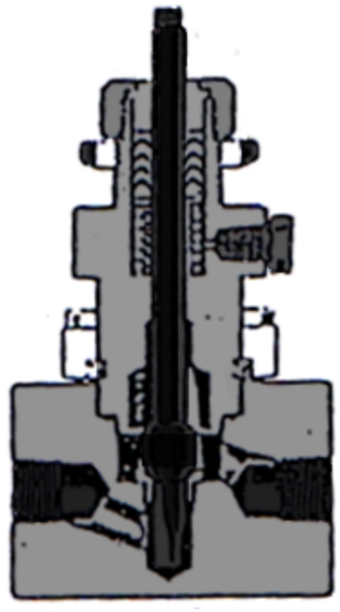
Double Port



3-Way

ii. Needle Type

- For high pressure usage. Used when a small flow at a big flow range is required.

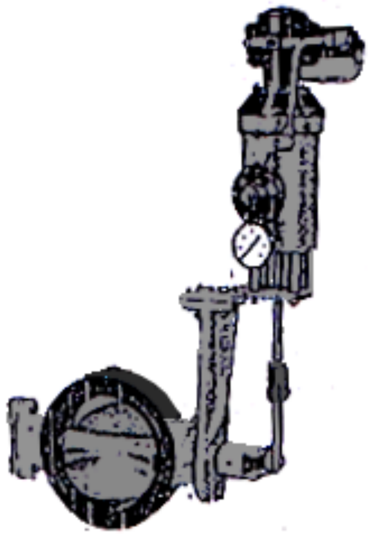


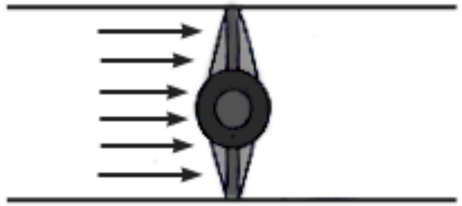
iii. Ball Type

- Consists of a solid ball and its cage.
- Provides a firm closing and a high range.
- Used for difficult to handle mediums such as pulp in the paper industry.

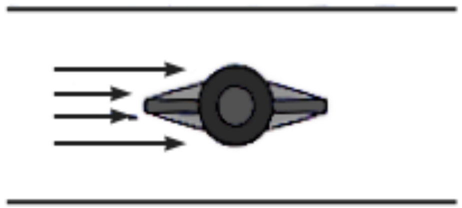
iv. Butterfly Type

- Consists of a vane or disk that is connected to a shaft where the vane can be rotated.
- Economical to use for big size application because of its simple and high capacity design.
- Low pressure drop.
- The valve is controlled at an angle of 10 – 60 degrees. The valve becomes unstable at a higher range of angle.

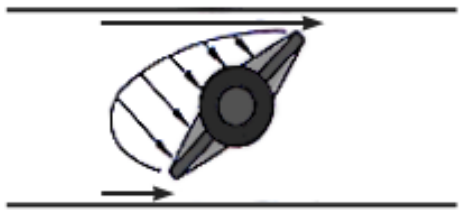




At 0°. forces are balanced.



At 90°. forces are balanced.

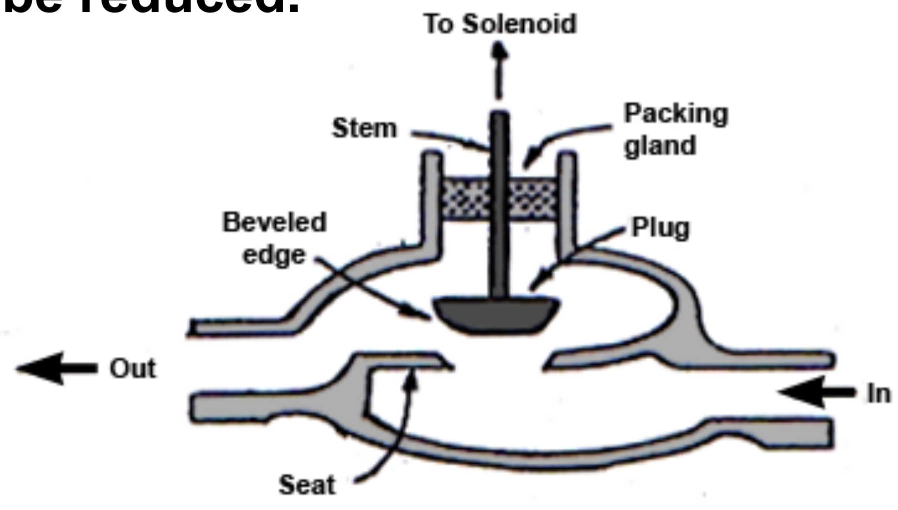


Between 0° and 90°.
forces are unbalanced.
lending to close disc.

Butterfly valve and the forces acting on the rotating disc

Shut Off Valve: Globe Valve

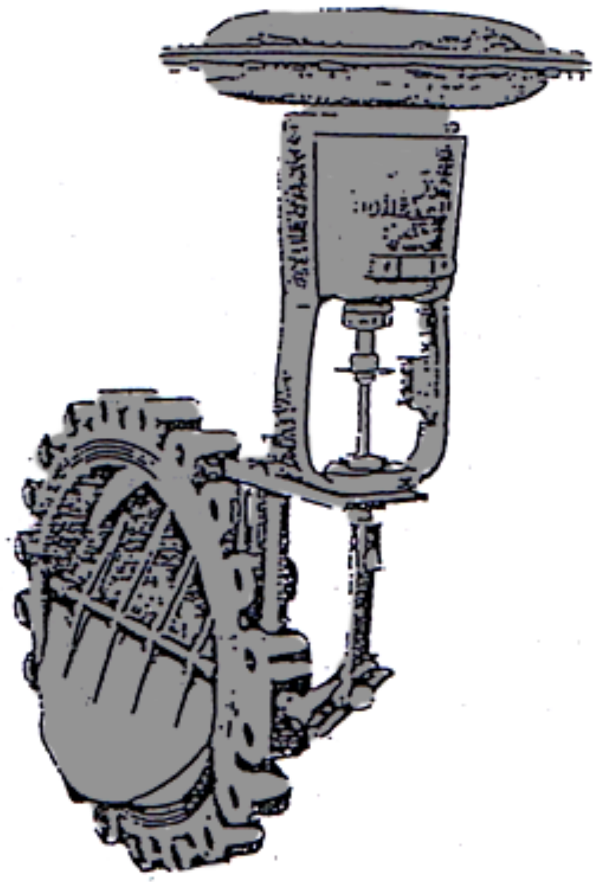
- Used for 100% opening/closing.
- plug – and seat type solenoid
- The flow of fluid is controlled by a moving plug. When the plug moves closer to the seat through the movement of the stem (which is determined by the solenoid), the valve opening and the flow of fluid will be reduced.



Solenoid operated plug and seat (global) valve

Throttling Valve: Butterfly Valve

- This valve consists of a circular vane which is pivoted to the body of the valve and is connected to the shaft which rotates with the movement of the actuator (rotary type, linear type).
- Suitable for semisolid fluid flow.



A butterfly valve

TYPES OF CONTROL VALVE OPENINGS

1. Quick Opening

- Used for full opening/closing.
- Minimum movement of stem allows maximum flow through valve.
- Usually 90% of maximum flow can be attained from 30% of stem movement.

2. Linear

- **The flow of fluid changes linearly with the position of stem .**

$$Q / Q_{max} = S / S_{max}$$

Q	: flow rate (m^3/s)
Q_{max}	: maximum flow rate (m^3/s)
S	: position of stem (m)
S_{max}	: maximum position (m)

3. Equal Percentage

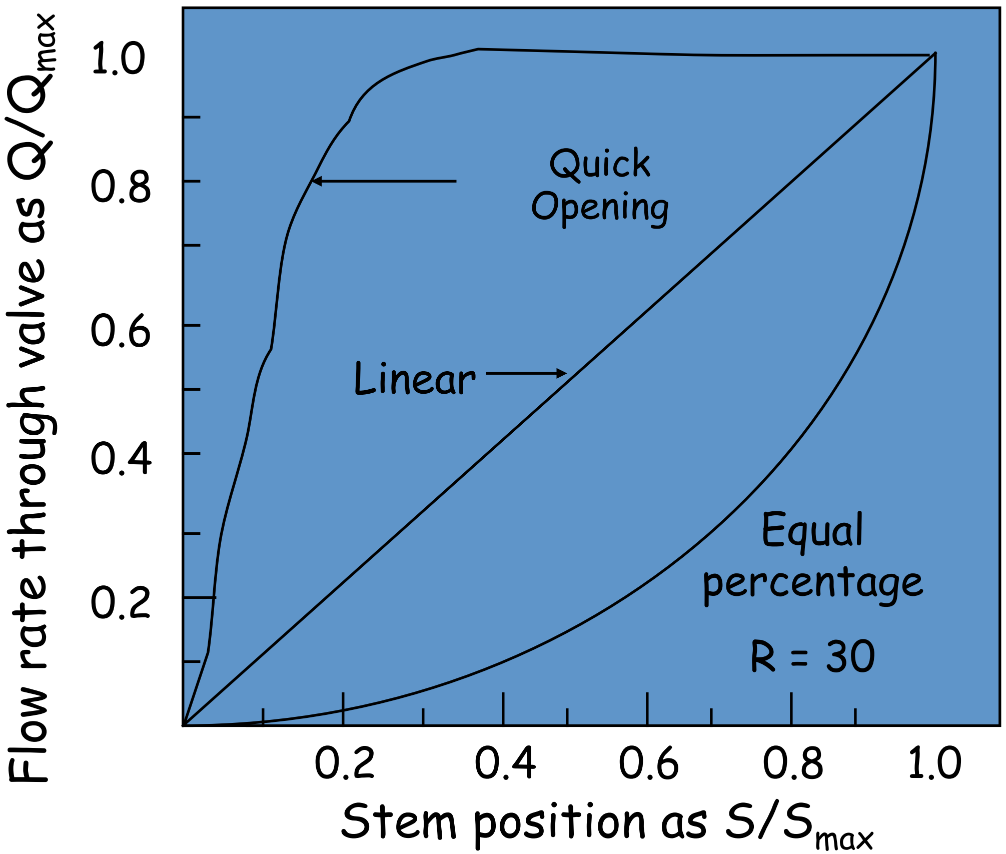
- This type of valve is important in flow control.
- The percentage in position change will give the same percentage of flow change.
- The flow does not need to be closed completely for this valve.
- Rangeability or R is the ratio of the inlet flow and the minimum flow.

  $R = Q_{max}/Q_{min}$

  Q_{max} : flow when valve is closed (at a certain limit).

  Q_{min} : minimum flow when stem is at a certain limit.
- The graph for this valve is an exponential valve and represented by the following equation:

  $$Q = Q_{min}.R^{S/Smax}$$


Flow rate through valve as Q/Qmax
1.0
0.8
0.6
0.4
0.2
Quick
Opening
Linear
Equal
percentage
R = 30
0.2
0.4
0.6
0.8
1.0
Stem position as S/Smax

Example

- **An equal percentage valve has a maximum flow of 50 cm^3/s and a minimum flow of 2 cm^3/s. If the maximum flow diameter is 3 cm, determine the flow rate when the opening is 1 cm.**

Rangeability = R = Q_{max}/Q_{min}

R = (50 cm^3/s) / (2 cm^3/s) = 25

Therefore, flow rate at 1 cm opening is:

$Q = Q_{min}.R^{S/Smax}$

$Q = (2\ cm^3/s).(25)^{1\ cm/3\ cm}$ = <u>5.85 cm^3/s</u>

IV. SIZING OF CONTROL VALVE

- An important factor because the right size of valve has to be determined.
- Table 1 is used to determine the right size of valve based on the following flow equation:

$$Q = C_v \sqrt{\Delta p / S_G}$$

Δp : pressure across the valve (psi)

S_G : specific gravity of liquid

C_v : valve flow coefficient (correction factor)

Table 1 : Control Valve Flow Coefficients

Valve Size (inches)	C_v
1/4	0.3
1/2	3
1	14
1 1/2	35
2	55
3	108
4	174
6	400
8	725

Example :

Determine :

a) The suitable C_v for a valve that allows the flow of 150 gallon ethyl alcohol in 1 minute with a specific gravity of 0.8 at a maximum pressure 50 psi.

b) The size of valve needed.

Answer:

a) $Q = C_v \sqrt{\Delta p / S_G}$

$C_v = Q \sqrt{S_G / \Delta p} = (150 \text{ gal/min}) \sqrt{(0.8) / (50 \text{ Ib/in}^2)}$

$\underline{C_v = 18.97}$

b) Referring to Table 1, the valve size needed is 1½ " diameter.