BECE312L
Robotics and Automation

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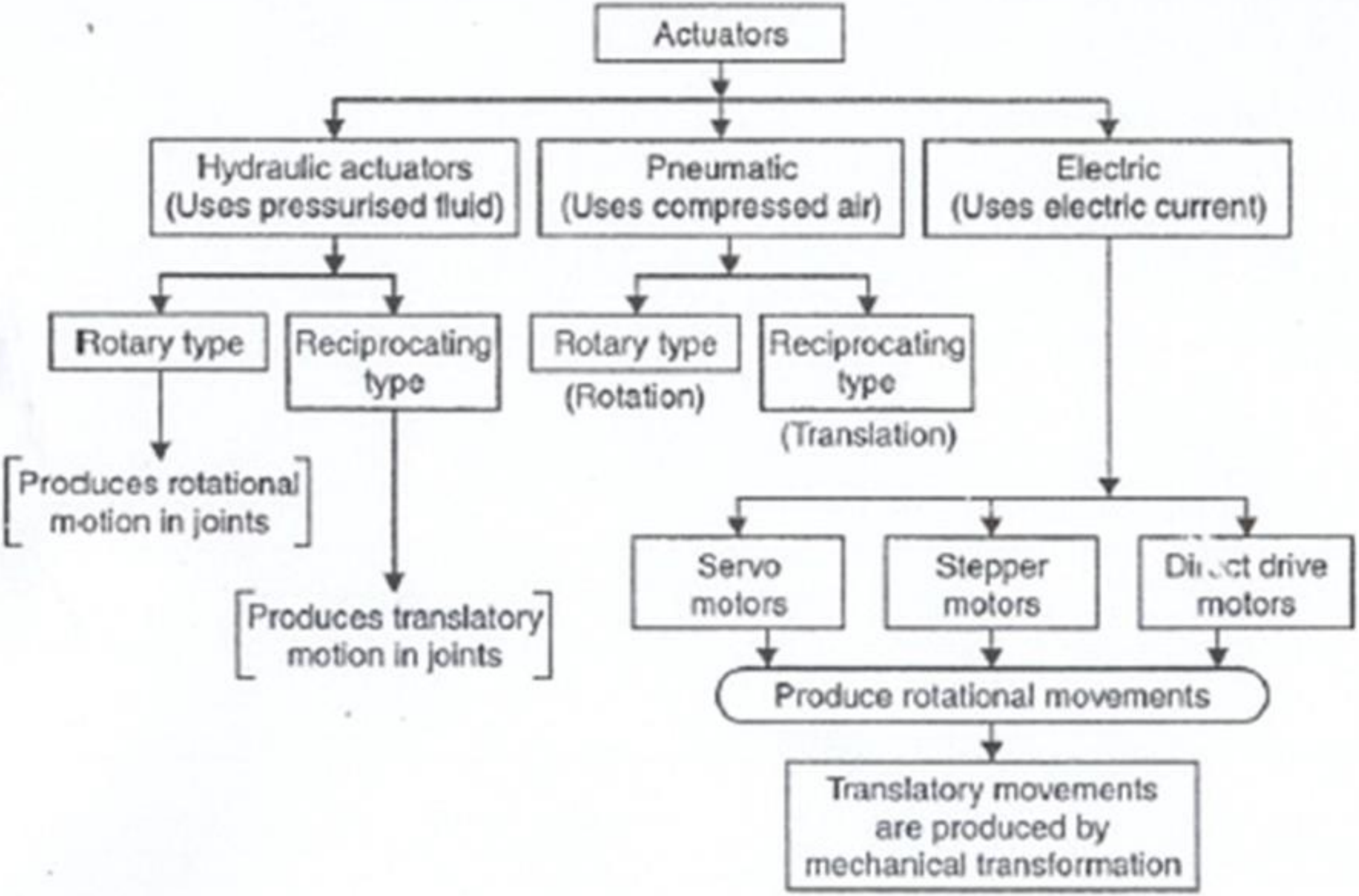
Module 2 -Drives for Robotics(3)

- Drives:
- Electric,
- hydraulic and
- pneumatic drives

Robot Drive Systems

- The term used for a mechanism that drives a Robot arm is actuator.
- Actuators are the muscles of robots
- These actuators may be electric motors of some type or hydraulic or pneumatic cylinders.
- Hydraulic and pneumatic actuators are generally suited to driving prismatic joints since they produce linear motion directly. They are often referred to as linear actuators.
- Electric motors which produce rotation are more suited to driving revolute joints. However various gear mechanisms may be used to convert linear to rotary motion and vice versa.


Actuators
Hydraulic actuators (Uses pressurised fluid)
Pneumatic (Uses compressed air)
Electric (Uses electric current)
Rotary type
Reciprocating type
Rotary type
(Rotation)
Reciprocating type
(Translation)
Produces rotational motion in joints
Produces translatory motion in joints
Servo motors
Stepper motors
Di ct drive motors
Produce rotational movements
Translatory movements are produced by mechanical transformation

Hydraulic actuators

Advantages

- Large lift capacity
- High power to weight ratio
- Moderate speeds
- Oil is incompressible, hence once positioned joints can be locked to a stiff structure
- Very good servo control can be achieved
- Self lubricating and self cooling
- Operate in stalled condition with no damage
- Fast response
- Intrinsically safe in flammable and explosive atmospheres
- Smooth operation at low speeds

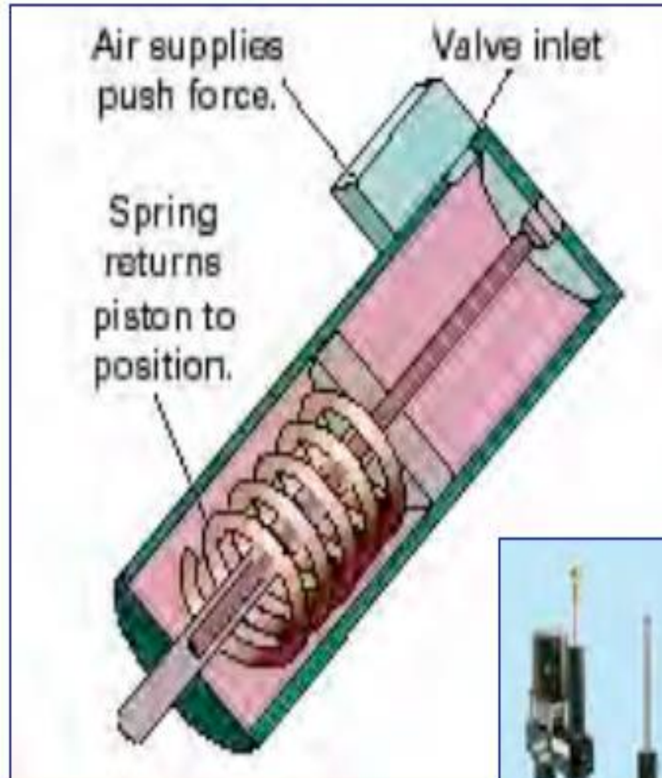
Disadvantages

- Hydraulic systems are expensive
- Maintenance problems with seals causing leakage
- Not suitable for high speed cycling
- Need for a return line
- Hard to miniaturize because high pressures and flow rates
- Need for remote power source which uses floor space
- Cannot back drive links against valves

Pneumatic actuators

Advantages

- Relatively inexpensive
- High speed
- Do not pollute work area with fluids
- Can be used in laboratory work
- No return line required
- Common energy source in industry
- Suits modular robot designs
- Actuator can stall without damage



Disadvantages

- Compressibility of air limits control and accuracy aspects
- Noise pollution from exhausts
- Leakage of air can be of concern
- Additional drying/filtering may be required
- Difficulties with control of speeds, take up of loads, and exhausting of lines

(DC motor and stepper motor)

(from McKerrow)

Electric actuators (DC motors and stepper motors)

Advantages

- Actuators are fast and accurate
- Possible to apply sophisticated control techniques to motion
- Relatively inexpensive
- Very fast development times for new models
- New rare earth motors have high torques, reduced weight, and fast response times

Disadvantages

- Inherently high speed with low torque, hence gear trains or other power transmission units are needed
- Gear backlash limits precision
- Electrical arcing may be a consideration in flammable atmospheres
- Problems of overheating in stalled condition
- Brakes are needed to lock them in position

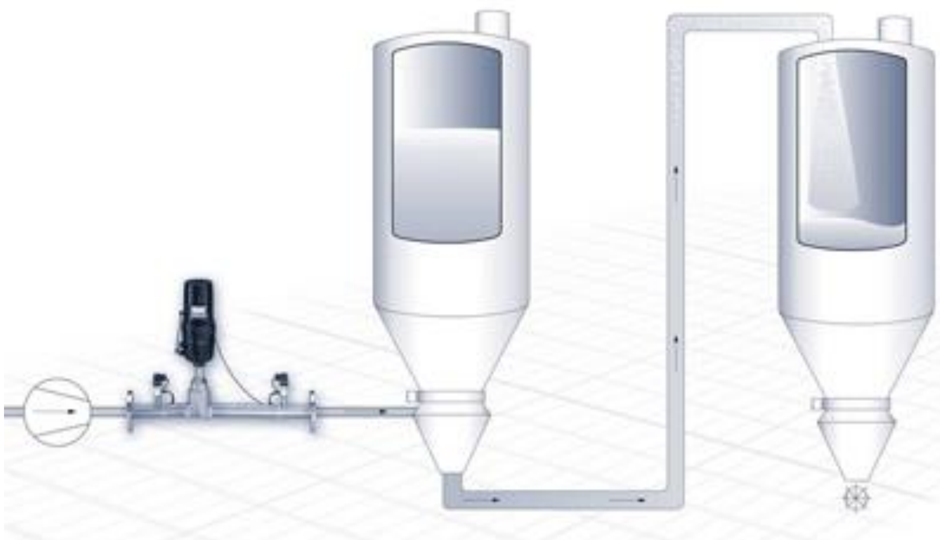
Hydraulic Actuators

- A common example of a hydraulic device is the braking system of a modern car, here only moderate force applied to the brake pedal produces a large enough force at the brake pads to stop the car. The underlying principle of all hydraulic systems is Pascal's Law, which states:-**If external pressure is applied to a confined fluid, the pressure is transferred without loss to all surfaces in contact with the fluid.**
- **Force x Distance moved at input = Force x Distance moved at output**
  Returning to the example of the car breaking system, it can now be easily explained. When the break pedal is pressed it travels a few centimetres, but the pistons which operate the brakes in the wheels move only one or two millimetres i.e. a small force applied to the brake pedal is used to produce a much larger force at the brakes.
-

Hydraulic/Pneumatic Systems

- Use fluids as working media
- Convert electrical/mechanical energy into potential energy of fluids (pump, compressor)
- Transmit power through distribution lines (pipes, air hoses)
- Convert potential energy of fluids/compressed gas into mechanical energy that turns linear/rotary actuators

Applications



Air Conveyor

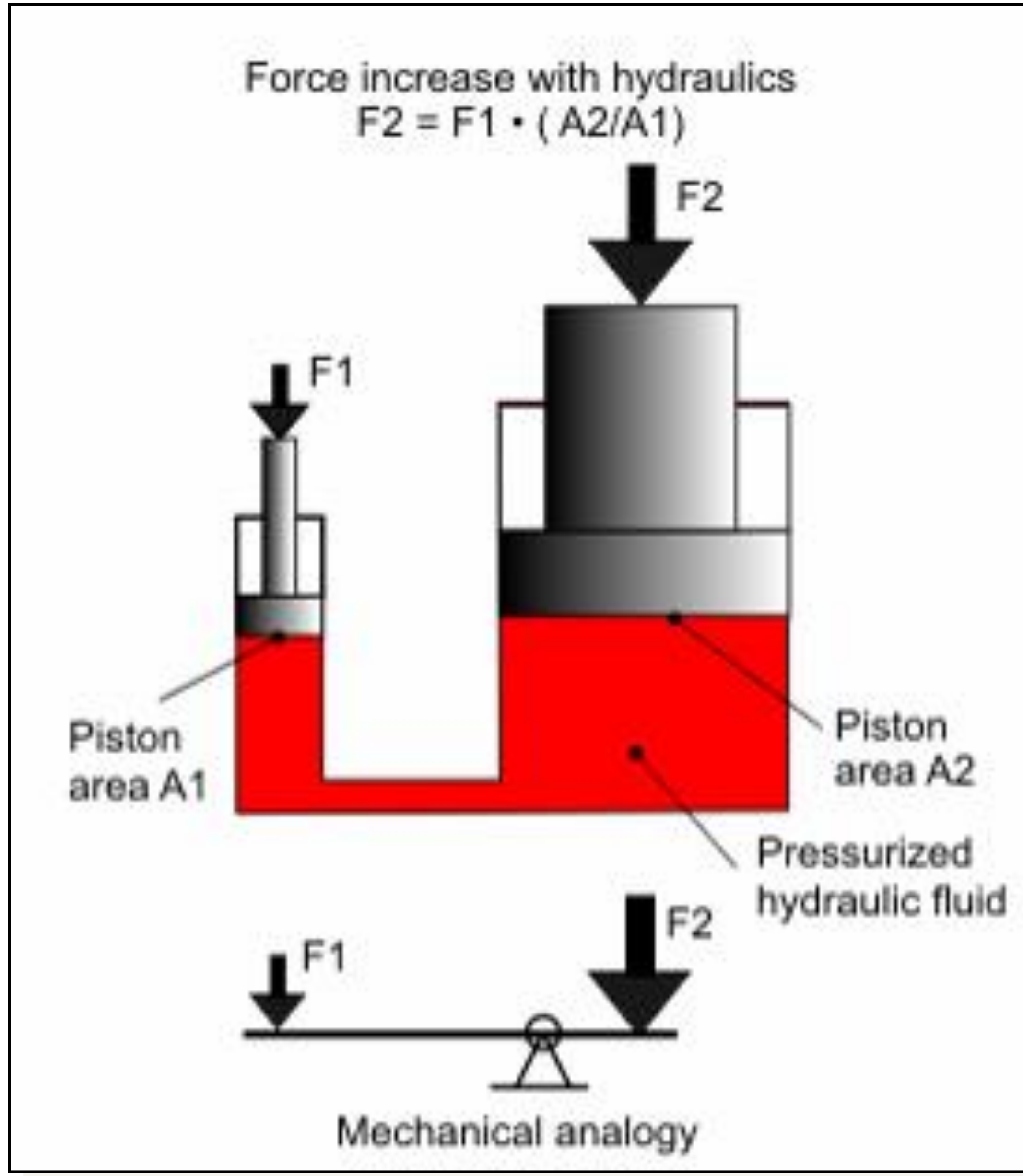
Impact Wrench

Hydraulic Jack

- Advantages
  - adaptable power distribution
  - **constant force actuators**
  - power amplification
  - inexpensive
- Disadvantages
  - difficult to control position
  - leaks and contamination of working fluid

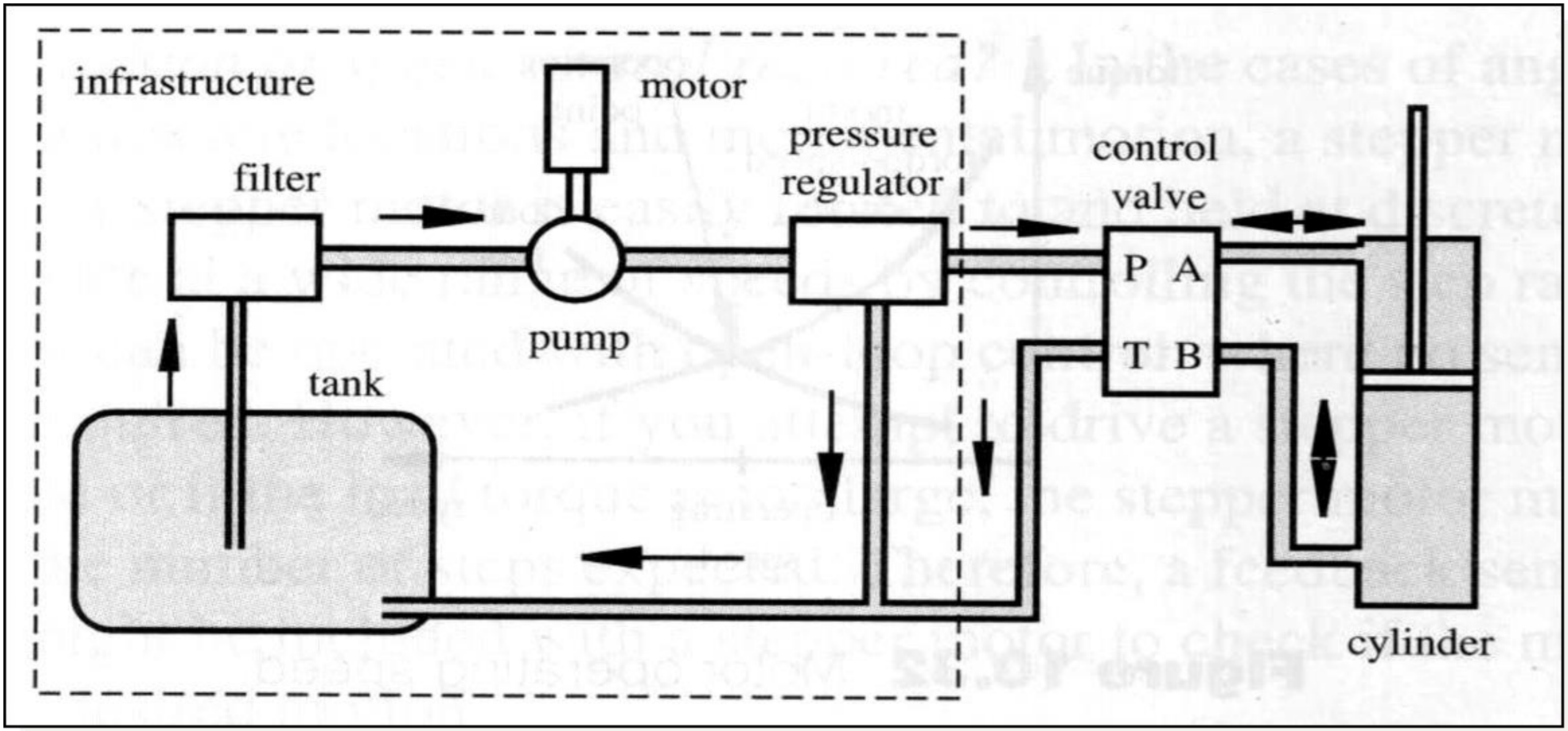
Pascal’s Law

- Pascal's law states that:
  "a change in the pressure of an enclosed incompressible fluid is conveyed undiminished to every part of the fluid and to the surfaces of its container.“
  - Force determined by pressure
  - Speed determined by flow rate



Hydraulic Systems

- Move large loads by controlling high-pressure fluid in distribution lines and pistons with mechanical or electromechanical valves
- 1000psi – 3000psi
- Closed systems, always recirculating same fluid



infrastructure
motor
filter
pressure
regulator
control
valve
P A
T B
pump
tank
cylinder

Hydraulic Systems

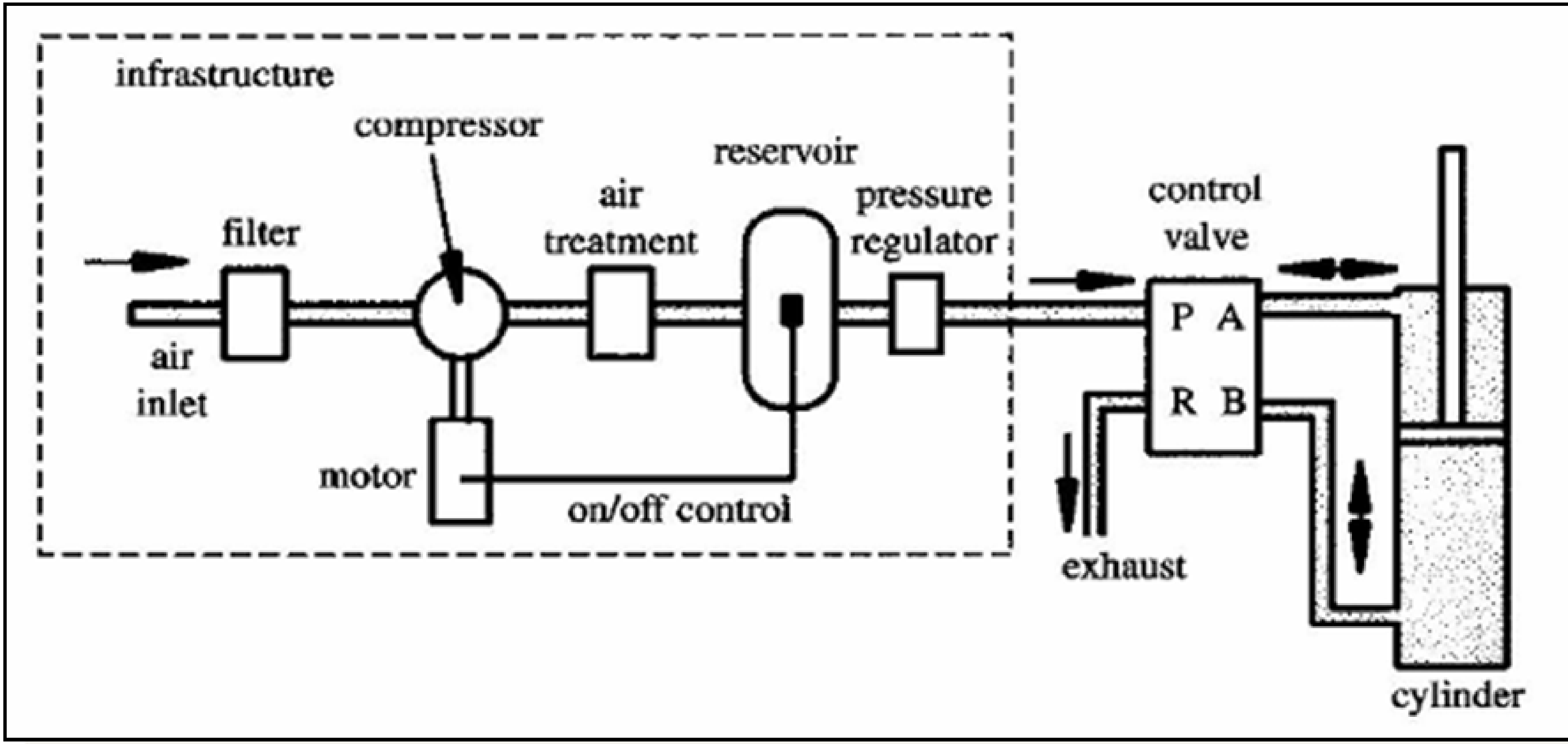
- Advantage:
  - Able to generate extremely large forces from compact actuators
  - Easy to control speed
  - Easy to implement linear motion
- Disadvantage:
  - Large infrastructure (high-pressure pump, tank, distribution lines)
  - Potential fluid leaks
  - Noisy operation
  - Vibration
  - Maintenance requirements, expensive
  - Characteristics of working fluids change with temperature and moisture

Pneumatic systems

- Pneumatic systems similar to hydraulic systems
- Use compressed air as working fluid rather than hydraulic liquid
- 70psi - 150psi, much lower than hydraulic system pressures, much lower forces than hydraulic actuators
- Energy can be stored in high pressure tanks
- Open systems, always processing new air

Pneumatic systems

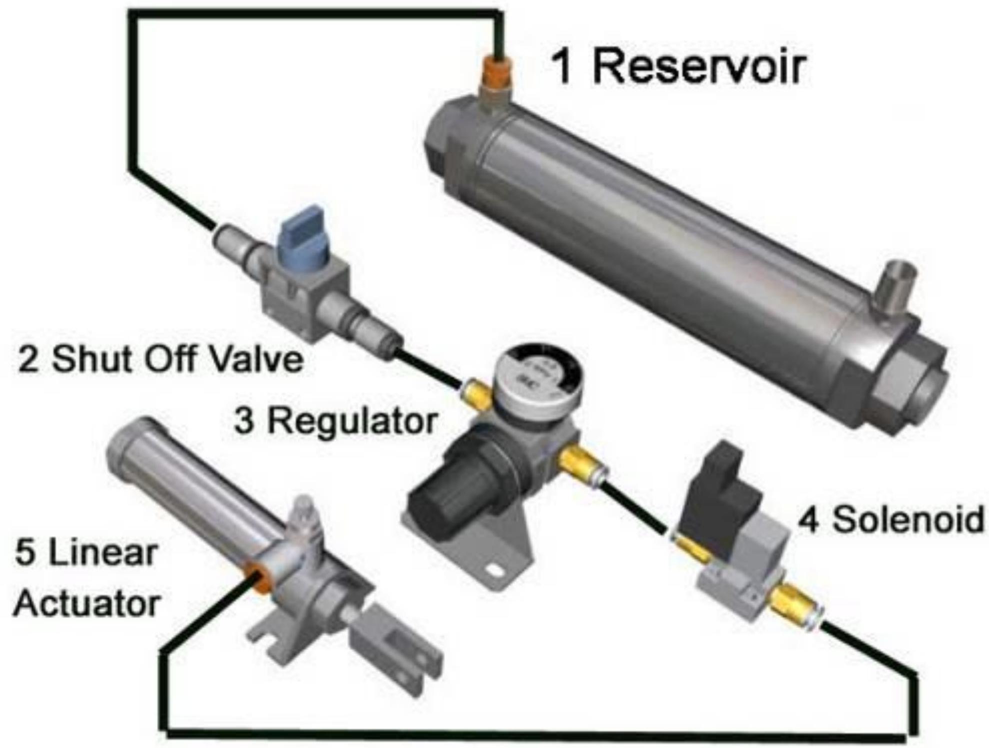
- Advantage:
  - Constant force
  - Clean (food industry)
  - No return lines needed
  - Adaptable infrastructure
  - Possible light, mobile pneumatic systems
  - Fast system response
- Disadvantage:
  - Difficult to achieve position control (compressible air)
  - Noisy



infrastructure
compressor
reservoir
air
treatment
pressure
regulator
filter
control
valve
P
A
R
B
air
inlet
motor
on/off control
exhaust
cylinder

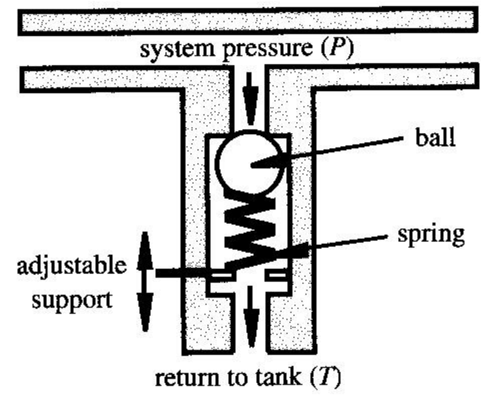
Key components of Hydraulic and Pneumatic

- Pump/Compressor
- Pressure regulator
- Valve
- Actuator

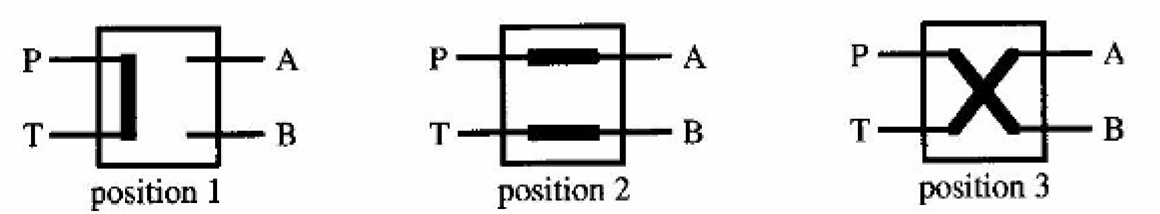


Valves

- Infinite position valve as shown in figure on right:
  - allows any position between open and closed to modulate flow or pressure
- Finite position valve:
  - has discrete positions, usually just open and closed, providing different pressure and flow condition
- Ports: inlet and outlet connections to valve
- Finite position valve usually specified as “x/y valve”
  - x: number of ports (sum of inlets and outlets)
  - y: number of positions
  - 4/3 valve: 4 ports and 3 positions

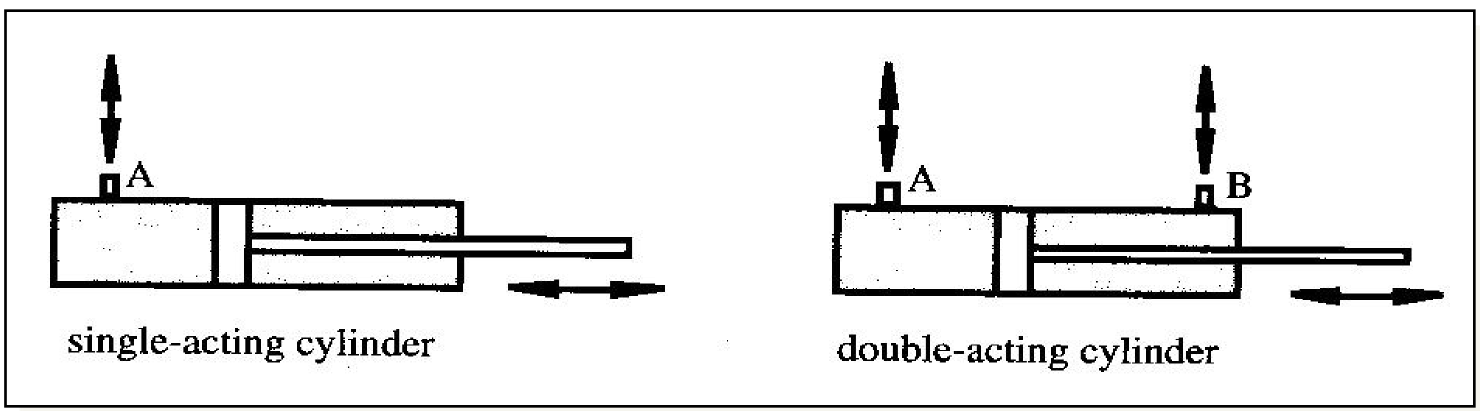


Pressure regulator



Hydraulic/Pneumatic actuators

- Cylinders with piston driven by pressurized fluid
- Single acting cylinder (SAC)
- Double acting cylinder (DAC)
- Two well-defined endpoints
- Rotary



Example 2: Anti-Lock Braking System

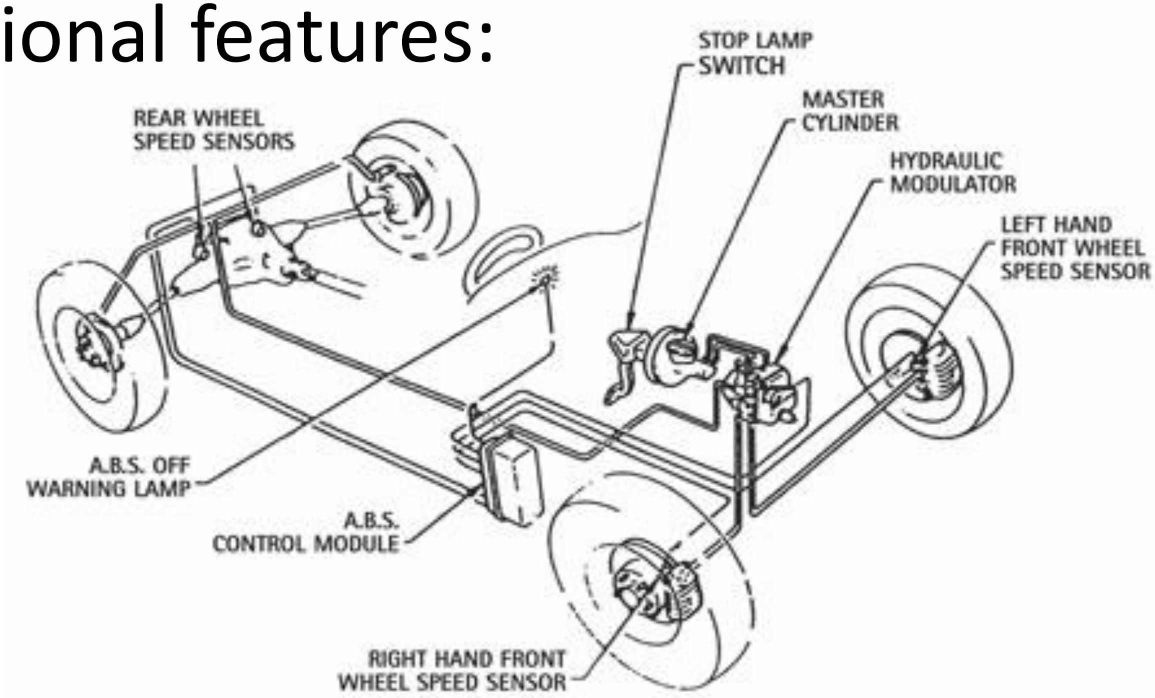
Regular Automobile Breaking System Includes:

•Hydraulic actuation

•Pneumatic power assist

ABS includes additional features:

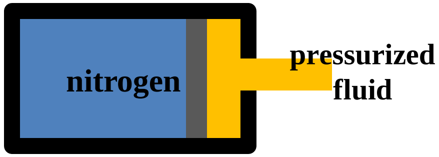
- sensors
- valves
- hydraulic pump
- control unit



Anti-lock Breaking System

- Wheel speed sensor

- Electric hydraulic pump
  - Stores fluid in pressurized chamber



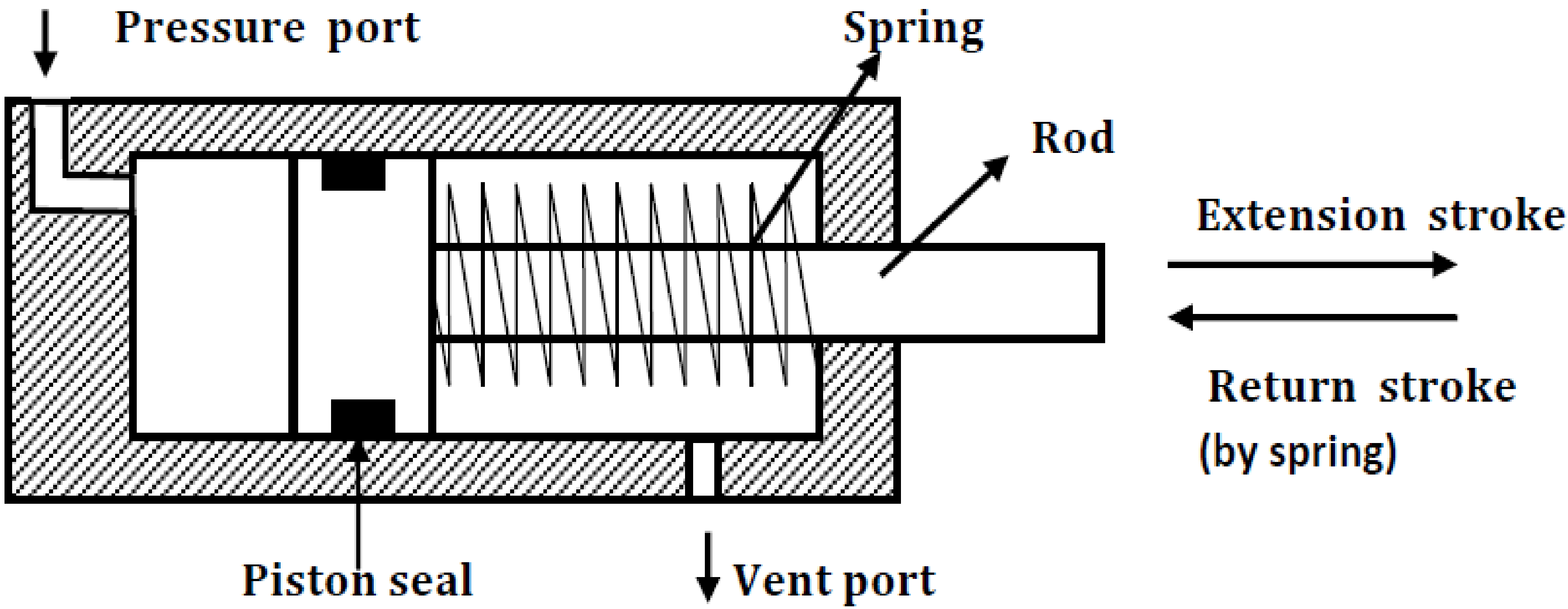
- Solenoid valves
  - Open: braking pressure supplied directly from master cylinder (under normal conditions)
  - Closed: isolate master cylinder pressure line (modulation)
  - Release: applies stored pressure to blocked break lines (modulation)

TYPES OF HYDRAULIC CYLINDERS

Hydraulic cylinder are of following types:

- **Single-acting cylinders**
- **Double-acting cylinders**
- **Telescopic cylinders**
- **Tandem cylinders**

SINGLE ACTING CYLINDER



SINGLE ACTING CYLINDER

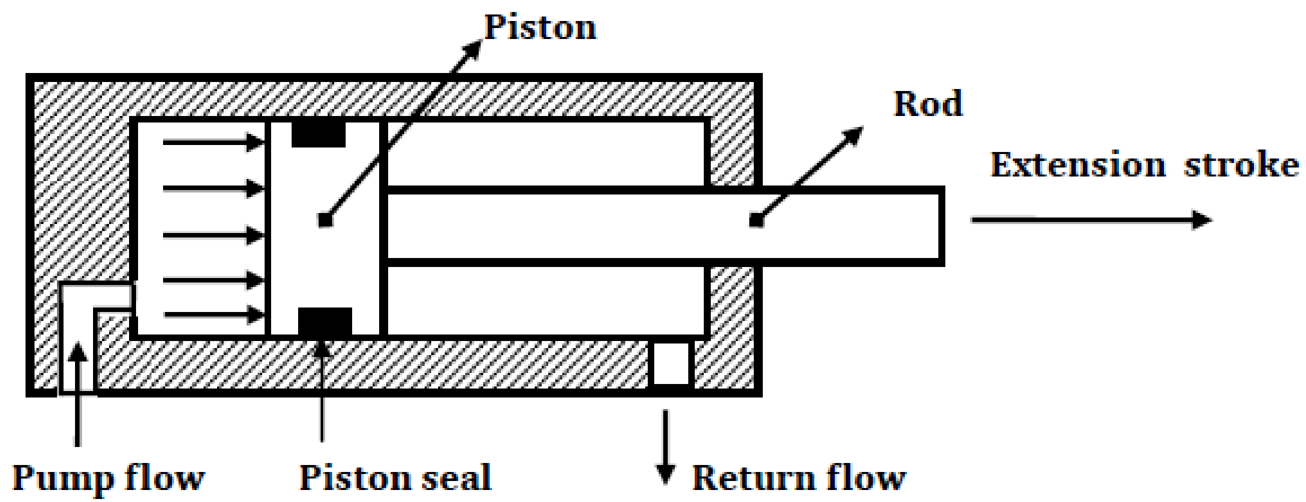
- It consist of piston inside a cylindrical housing called as barrel
- On one end is attached a rod, which can reciprocate
- At the opposite end, there is a port for the entrance and exit of the oil
- They produce force only in one direction by hydraulic pressure acting on the piston
- The return of the spring is not done hydraulically, it is either done by gravity or spring.

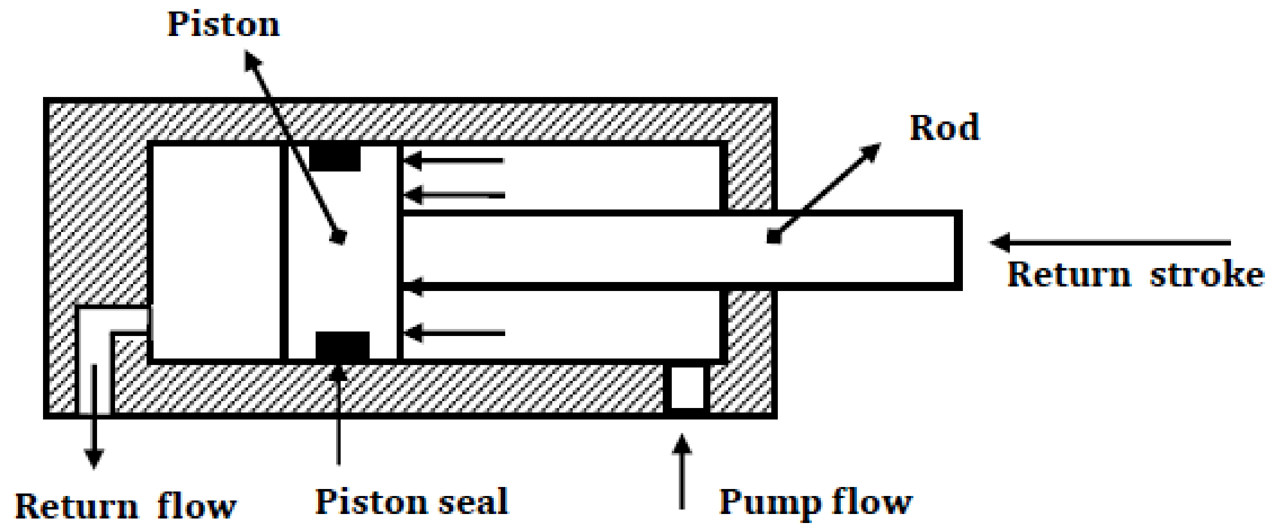
DOUBLE ACTING CYLINDER

There are two types of double acting cylinder:

- **Double acting cylinders with piston rod on one side**
- **Double acting cylinders with piston rod on both side**

DOUBLE ACTING CYLINDER





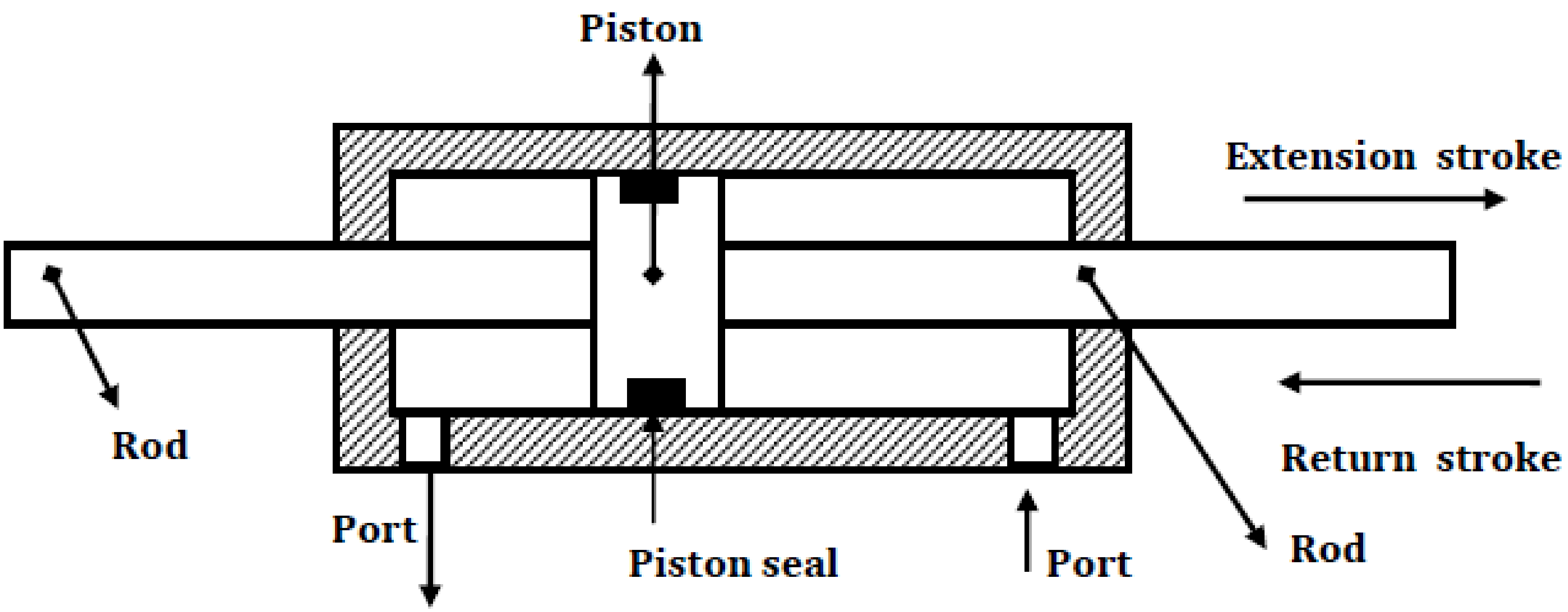
DOUBLE ACTING CYLINDER

DOUBLE ACTING CYLINDER WITH PISTON ROD ON ONE SIDE

- **To extend the cylinder, the pump flow is sent to the blank-end port as shown in fig.**
- **The fluid from the rod end port returns to the reservoir**
- **Now to retract the cylinder, the pump flow is sent to the rod end port and the fluid from the blank end port returns to the tank as shown in another fig.**

DOUBLE ACTING CYLINDER

DOUBLE ACTING CYLINDER WITH A PISTON ROD ON BOTH SIDES



DOUBLE ACTING CYLINDER

- A double acting cylinder with piston on both sides is a cylinder with a rod extending from both the ends
- The application involves in a process where work can be done by both the ends of the cylinder, thereby making the cylinder more productive
- Double rod cylinder can withstand higher side loads because they have an extra bearing on each rod to withstand the loading.

TELESCOPIC CYLINDER

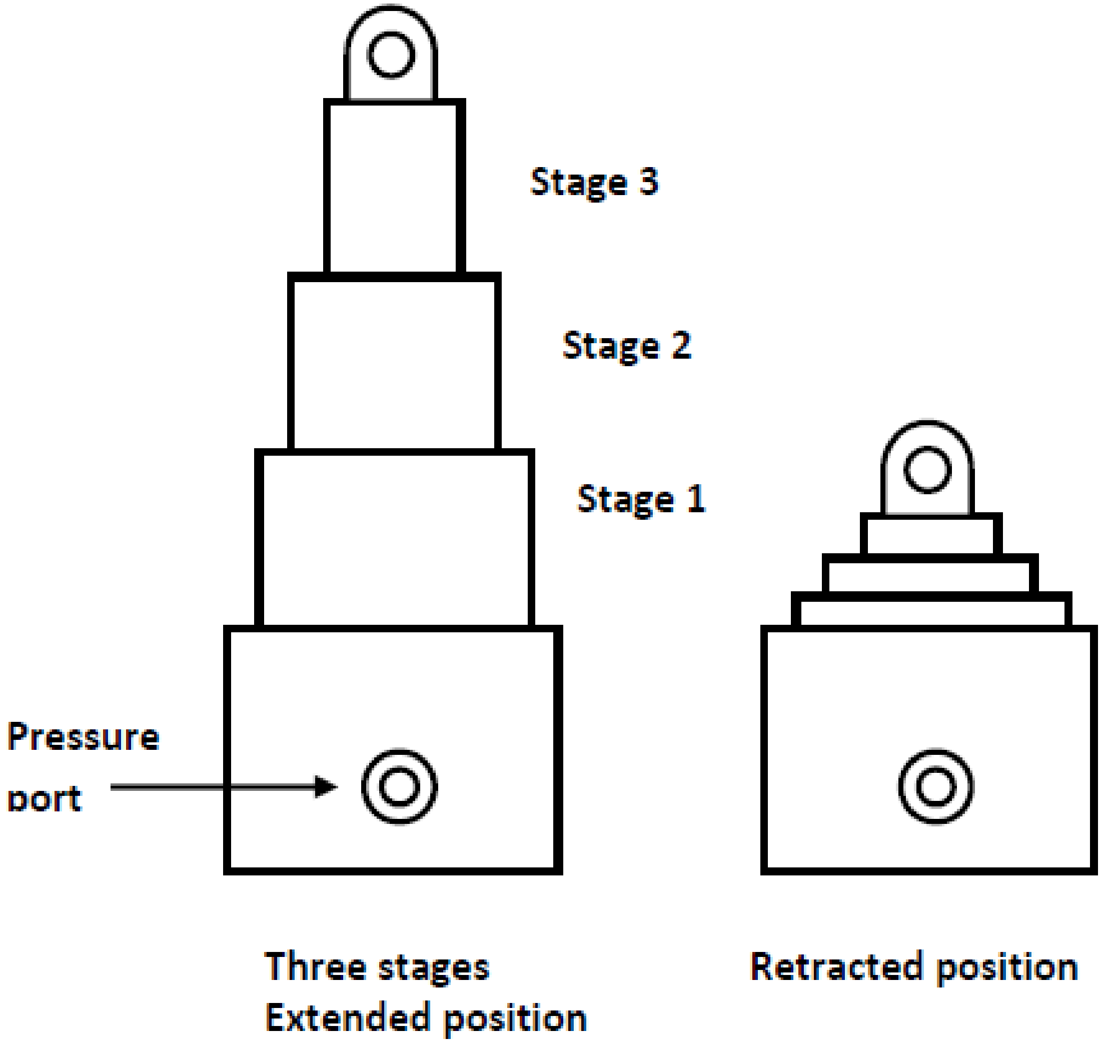
A telescopic cylinder is needed when a long stroke length and a short retracted length are needed.

The telescopic cylinder extends in stages, each stage consisting of a sleeve that fits inside the previous stage

One application for this type of cylinder is raising a dumping truck bed.

Telescopic cylinders are available both in single acting and double acting models.

TELESCOPIC CYLINDER

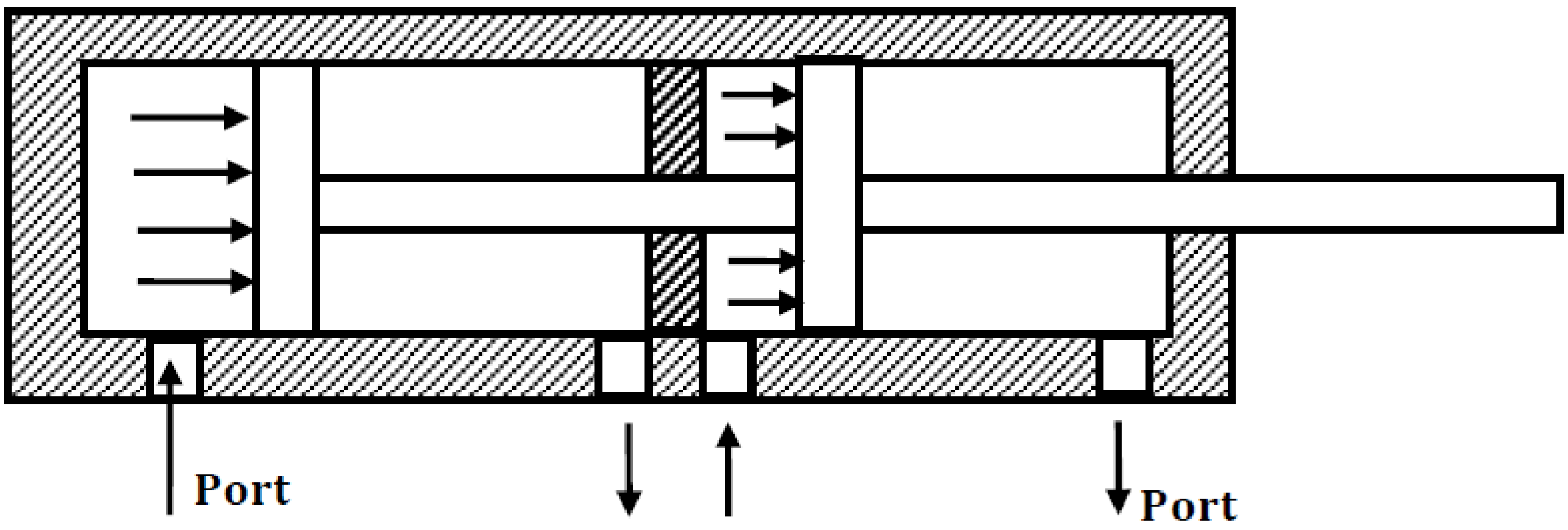


TELESCOPIC CYLINDER

Construction:

- **They generally consist a nest of tubes and operate on the displacement principle**
- **The tubes are supported by bearing rings, the innermost set of which have grooves or channels to allow the fluid flow**
- **The front bearing assembly on each section includes seals and wiper rings**
- **Stop rings limit the movement of each section, thus preventing the separation**
- **For a given input flow rate, the speed of operation increases in steps as each successive section reaches the end of its stroke. Similarly, for a specific pressure, the load shifting capacity decreases for each of the successive section**

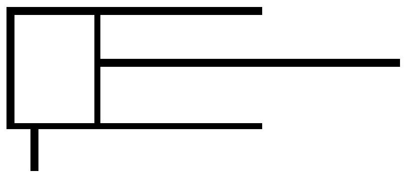
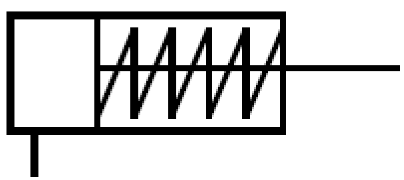
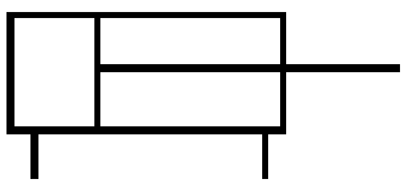
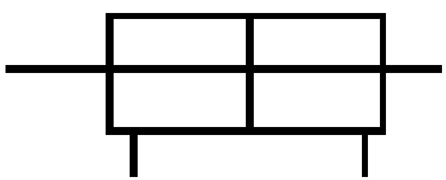
TANDEM CYLINDER



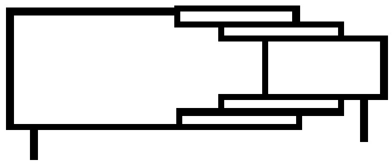
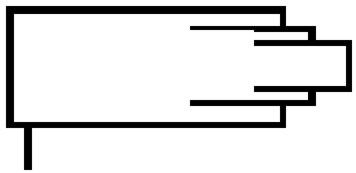
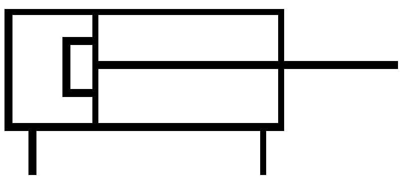
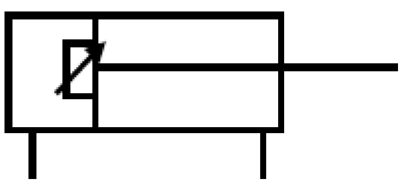
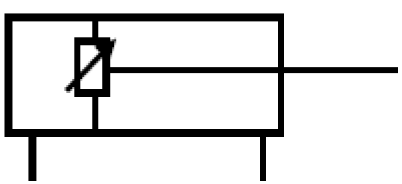
TANDEM CYLINDER

- A tandem cylinder is used in application where a large amount of force is required to be applied from a small diameter cylinder
- Pressure is applied to both the pistons, resulting in a increased force because of a large area.
- The only drawback is that this cylinders must be longer than a standard cylinder to achieve an equal speed because the flow must go to both the pistons simultaneously.

GRAPHICAL SYMBOLS

S. No.	Graphical Symbols	Explanation
1.		Single-acting cylinder with unspecified return
2.		Single-acting cylinder with spring return
3.		Double-acting cylinder –single piston rod
4.		Double-acting cylinder –doublepiston rod

GRAPHICAL SYMBOLS

5.		Telescopic cylinder–double acting
6.		Telescopic cylinder–single acting
7.		Double-acting cylinder– fixed cushion on one side
1.		Double-acting cylinder–variable cushion on one side
9.		Double-acting cylinder–variable cushion on both sides

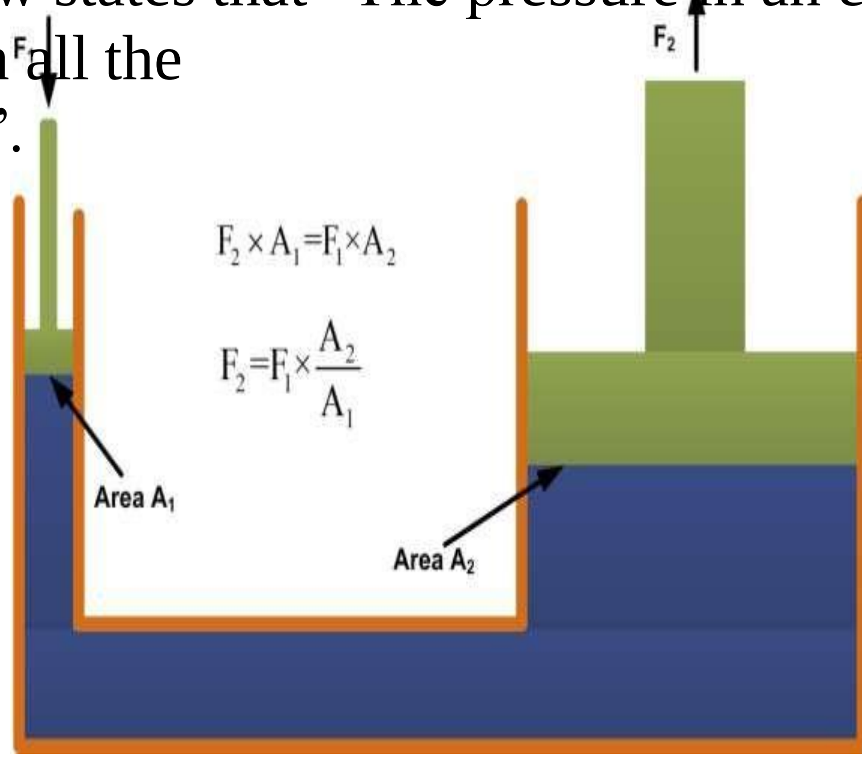
HYDRAULIC CONTROL SYSTEMS

INTRODUCTION

- The controlled movement of parts or a controlled application of force is a common requirement in the industries.
- These operations are performed mainly by using electrical machines or diesel, petrol and steam engines as a prime mover.
- The enclosed fluids (liquids and gases) can also be used as prime movers to provide controlled motion and force to the objects or substances.
- The specially designed enclosed fluid systems can provide both linear as well as rotary motion.
- This kind of enclosed fluid based systems using

PRINCIPLE OF HYDRAULIC SYSTEM

- The Hydraulic System works on the principle of **Pascal's law**.
- Pascal's law states that "The pressure in an enclosed fluid is uniform in all the directions".

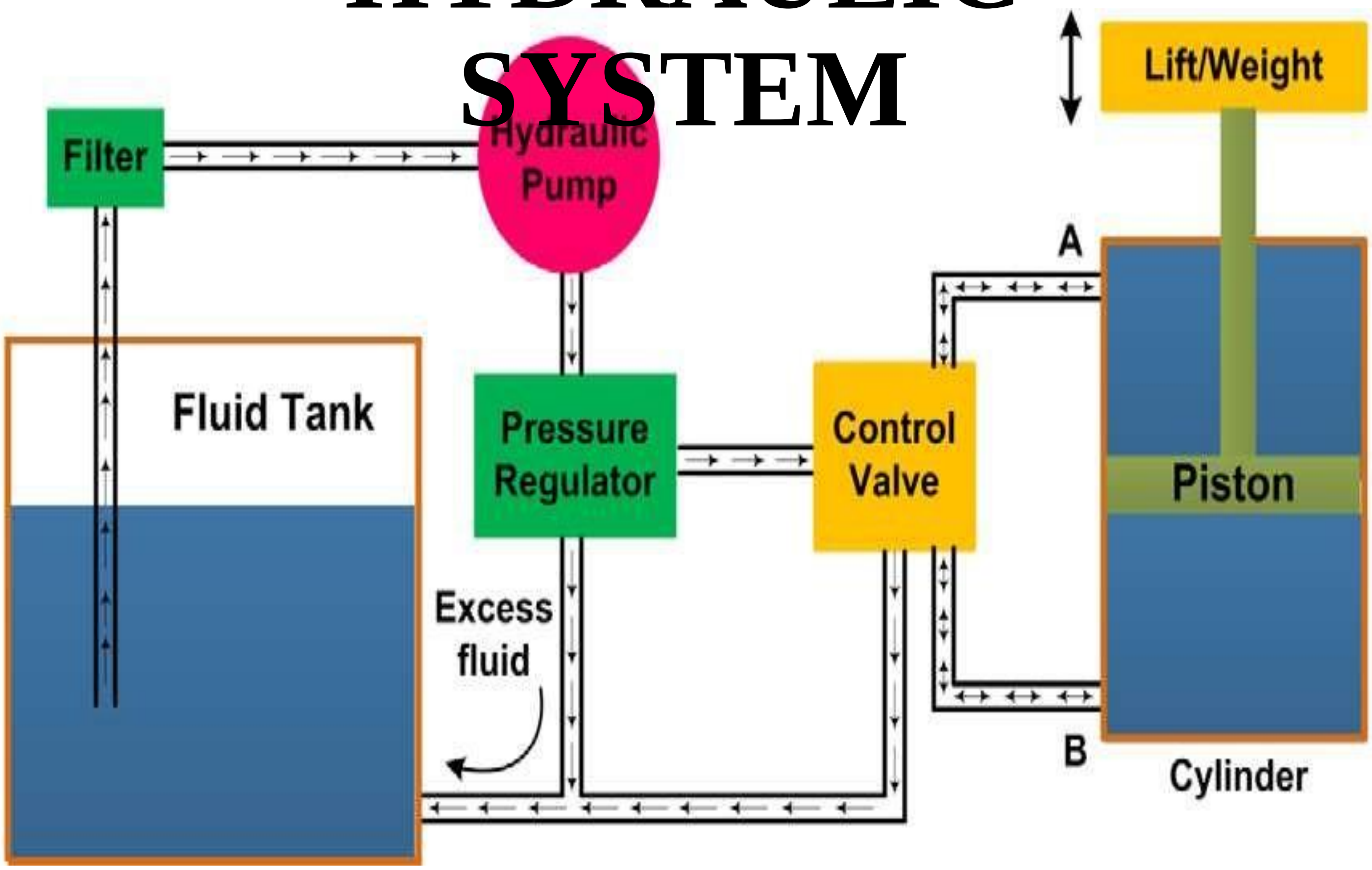


COMPONENTS OF HYDRAULIC SYSTEM

- **The major components of a hydraulic system are:**

1. Prime Mover
2. Pump
3. Control Valves
4. Actuators(Hydraulic motors, pistons)
5. Piping System
6. Fluid

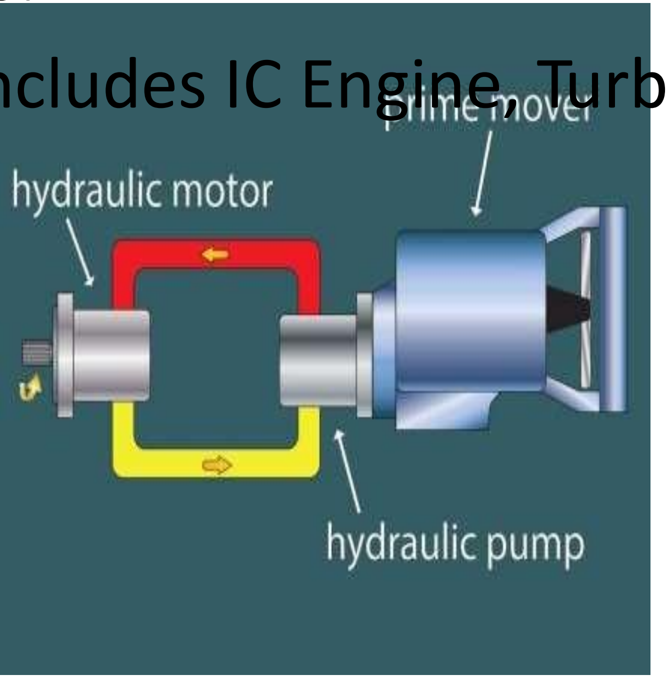
SCHEMATIC DIAGRAM OF HYDRAULIC SYSTEM



I. PRIME MOVERS

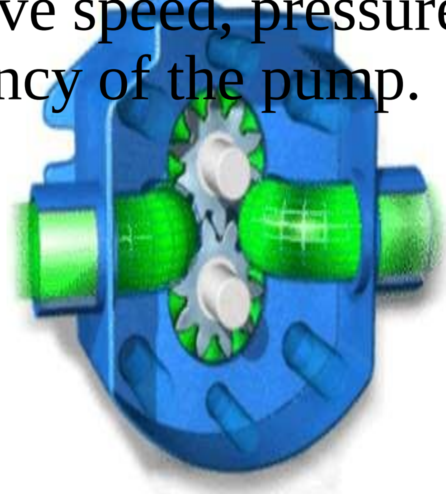
- Prime mover is a device which develops the mechanical power.
- This power in a hydraulic system is basically used to drive the pump.

Prime mover includes IC Engine, Turbines, etc



II. HYDRAULIC PUMPS

- Pump is a device which converts mechanical energy to fluid energy.
- The hydraulic pump takes hydraulic fluid (mostly some oil) from the storage tank
  and delivers it to the rest of the hydraulic circuit.
- The hydraulic pumps are characterized by its flow rate capacity, power consumption, drive speed, pressure delivered at the outlet and efficiency of the pump.



TYPES OF HYDRAULIC PUMPS

- **Non-positive displacement pumps:**

✓Known as hydro-dynamic pumps

✓Fluid is pressurized by the rotation of the propeller and the fluid pressure is proportional to the rotor speed

✓Used for low-pressure and high-volume flow applications

✓Eg: Centrifugal Pumps

- **Positive displacement pumps:**

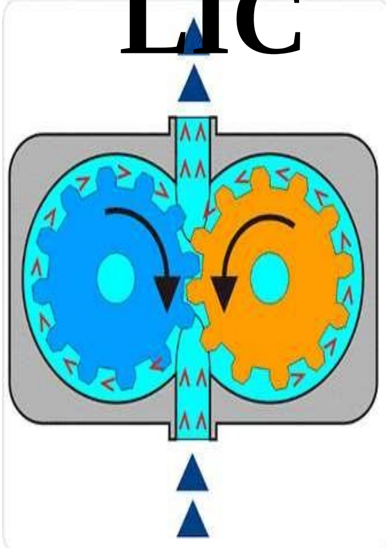
✓These pumps deliver a constant volume of fluid in a cycle

✓Used in most of the industrial fluid power applications

✓The output fluid flow is constant and is independent of the system pressure

✓Eg: Vane pump, Piston Pump, Gear Pump

HYDRAULIC GEAR PUMPS



External Gear Pumps

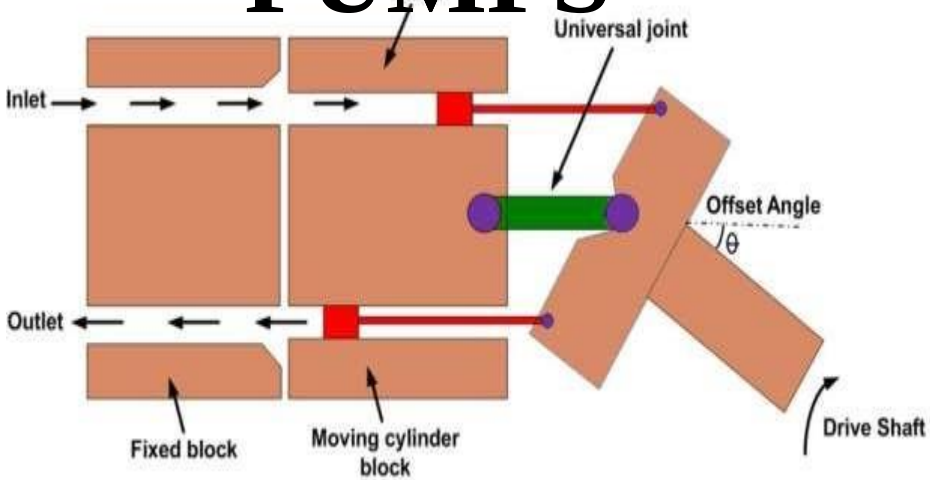
Internal Gear Pumps

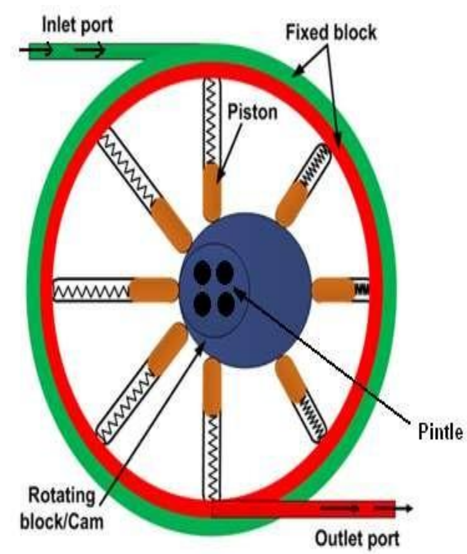
Gerotor Pump

Lobe Pump

HYDRAULIC VANE PUMPS

HYDRAULIC PISTON PUMPS





III. CONTROL VALVES

- The control of the mechanical outputs (motion and force) is one of the most important functions in a hydraulic system.
- The proper selection of control selection ensures the desired output and safe function of the system.
- In order to control the hydraulic outputs, different types of control valves are required.
- There are basically three types of valves employed in hydraulic systems:

1. Directional control valves
2. Flow control valves
3. Pressure control valves

DIRECTIONAL CONTROL VALVES

- Directional control valves provide the direction to the fluid and allow the flow in a particular direction.
- These valves are used to control the start, stop and change in direction of the fluid flow.
- They can be classified in the following manner:

➢ **Type of construction:**

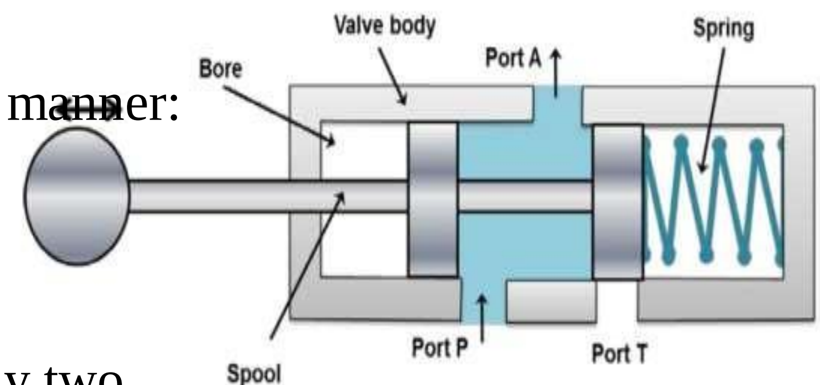
1. Poppet valves
2. Spool valves

➢ **Number of ports and switching positions:**

1. Three way two position
2. Four way three position
3. Four way two position

➢ **Method of change over from one position to next:**

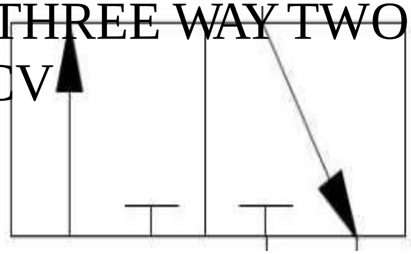
1. Non throttling type
2. Throttling



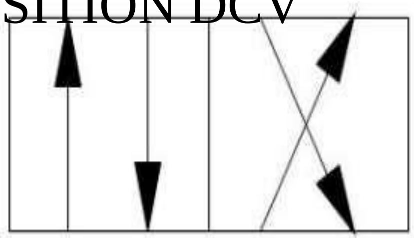
THREE WAY VALVE

- Directional control valves are generally specified using the number of ports and the number of switching positions. It can be represented in general form as n_p/n_s, where n_p is the number of ports connected to the direction control valve and n_s the number of switching positions.

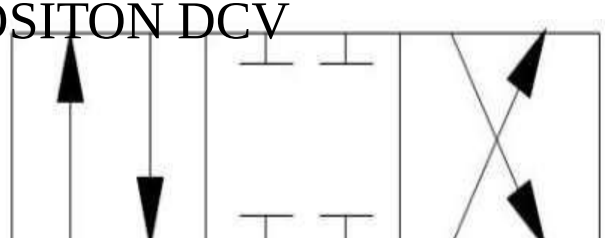
❖THREE WAY TWO POSITION DCV

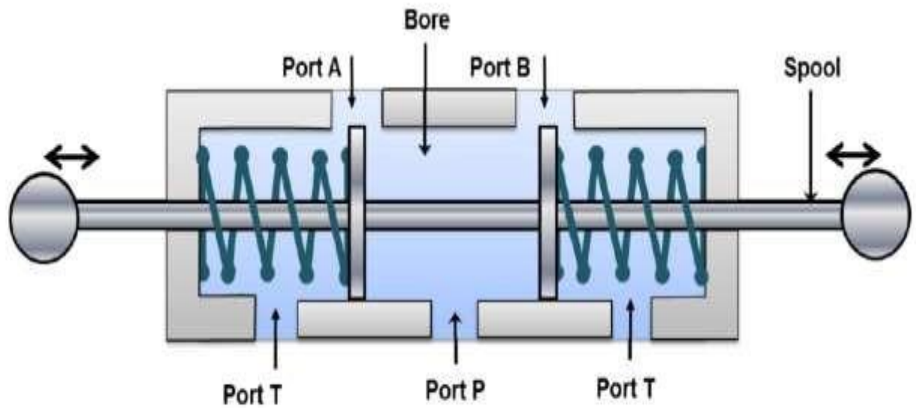


❖FOUR WAY TWO POSITION DCV



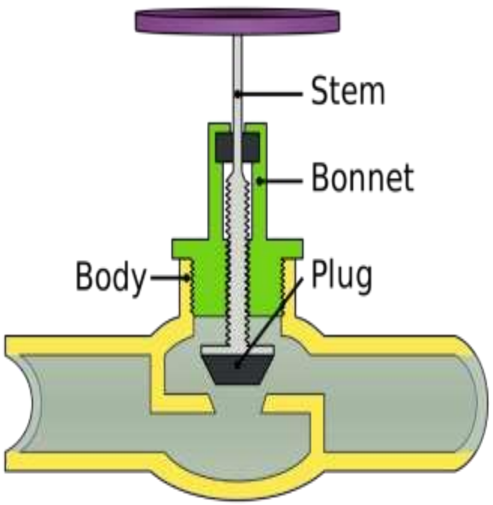
❖FOUR WAY THREE POSITON DCV

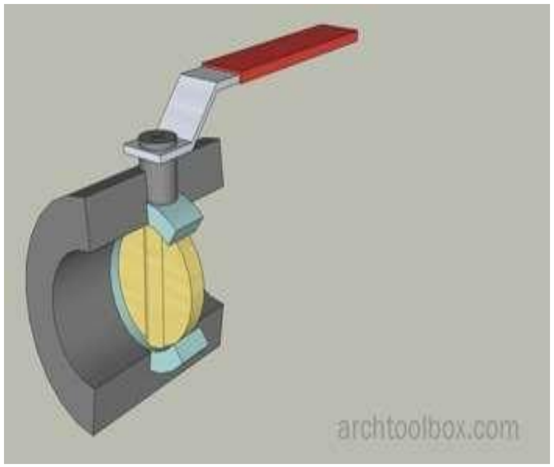


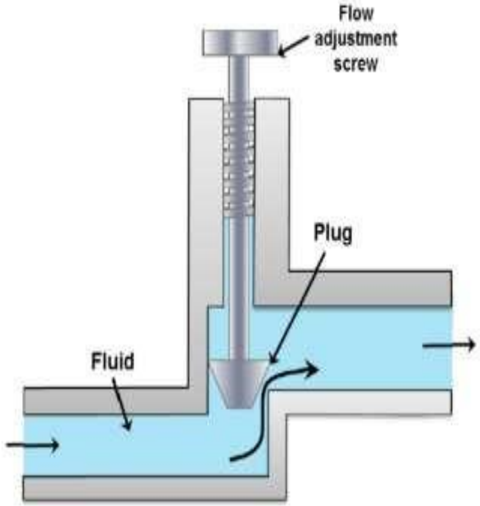


FOUR WAY THREE POSITION DCV

FLOW CONTROL VALVES







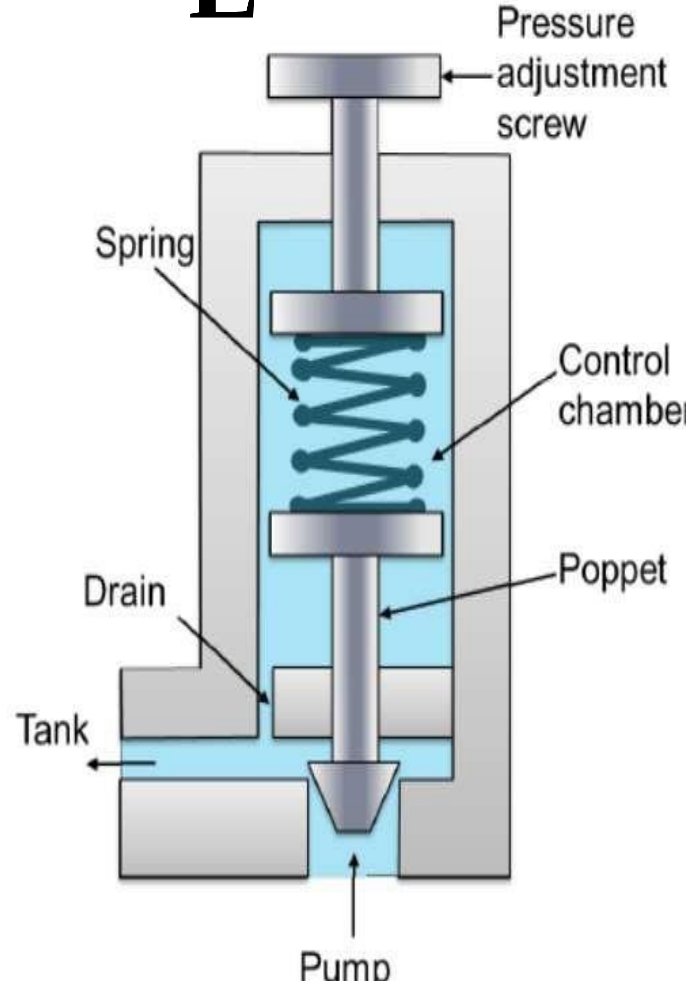
GLOBE VALVE

BUTTERFLY VALVE

PLUG VALVE

PRESSURE CONTROL VALVE

- The pressure control valves are used to protect hydraulic components from excessive pressure.
- It is normally a closed type and it opens when the pressure exceeds a specified maximum value by diverting pump flow back to the tank.
- Pressure control valves are the functional part of the system.



IV. HYDRAULIC ACTUATORS

- Hydraulic Actuators employ hydraulic pressure to drive an output member.
- These are used where high speed and large forces are required.
- The fluid used in hydraulic actuator is highly incompressible.
- They convert fluid power into mechanical power.
- Depending on motion they can be classified as:

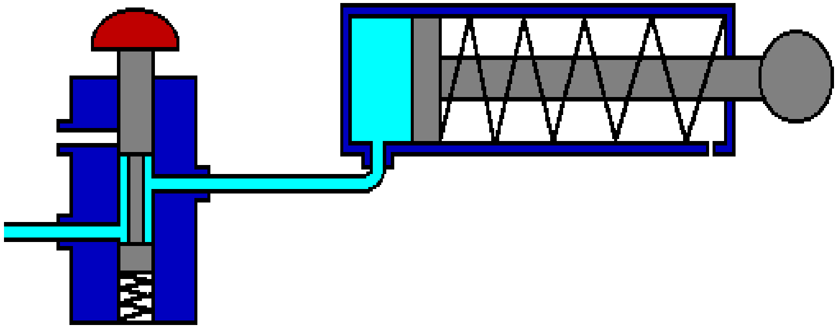
1. **Linear actuators:** linear motion as output(cylinder and piston)
2. **Rotary actuator:** rotary motion as output(motor)

HYDRAULIC CYLINDERS

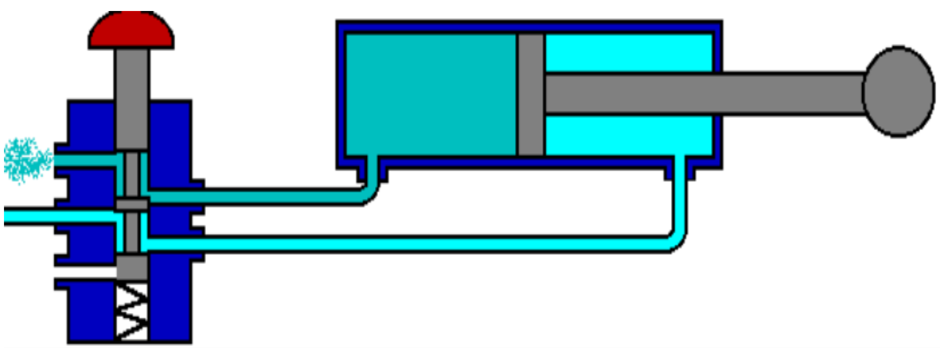
- Cylinders are linear actuators, that is, they produce straight-line motion and/or force.
- Cylinders are classified as:

1. Single-acting Cylinder
2. Double-acting Cylinder

- Single Acting Cylinder has only one fluid chamber and exerts force in only one direction.
- The double-acting cylinder is operated by hydraulic fluid in both directions and is capable of a power stroke either way.

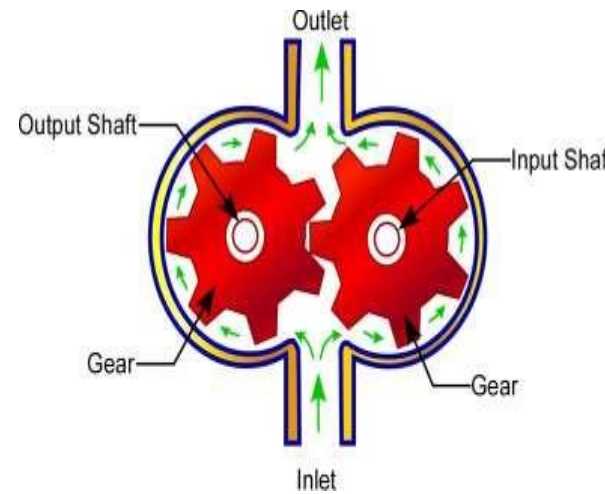


SINGLE ACTING CYLINDER



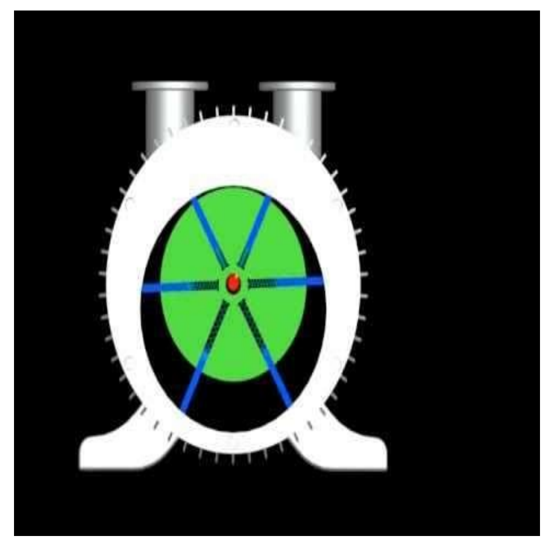
DOUBLE ACTING CYLINDER

HYDRAULIC MOTORS



- Motors work exactly on the reverse principle of pumps.
- In motors fluid is forced into the motor from pump outlet at high pressure is converted to mechanical energy.
- This fluid pressure creates the motion of the motor shaft.
- Though any pump can be used as motor, the commonly used hydraulic motors are:

1. Vane Motors
2. Gear Motors
3. Piston



V. HYDRAULIC FLUID

- Hydraulic fluid must be essentially non-compressible to be able to transmit power instantaneously from one part of the system to another.
- At the same time, it should lubricate the moving parts to reduce friction loss and cool the components so that the heat generated does not lead to fire hazards.
- The most common liquid used in hydraulic systems is petroleum oil because it is only very slightly compressible.
- **Properties of hydraulic fluids:**

1. Non compressible
2. Low volatility
3. Corrosion control
4. Fire resistance

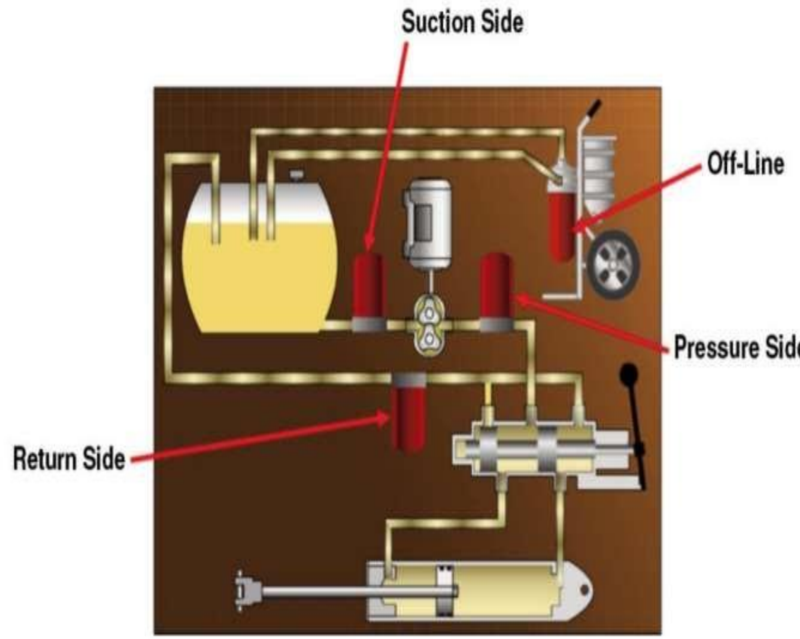
VI. FILTERS

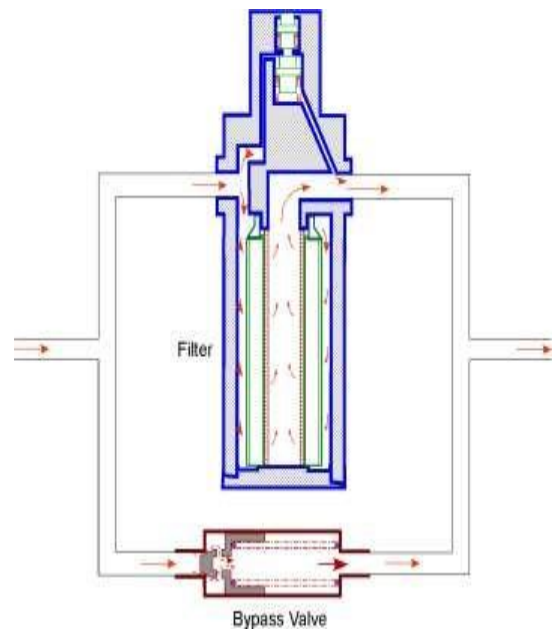
- The hydraulic fluid is kept clean in the system with the help of filters and strainers.
- It removes minute particles from the fluid, which can cause blocking of the orifices of servo-valves or cause jamming of spools.
- **Types of hydraulic filters:**

1. **Suction Filters:** The suction filter provides protection to the hydraulic pump from particles larger than 10 microns.
2. **Pressure Side Filters:** Located downstream from the hydraulic pump, these filters are designed to clean the fluid as it exits the pump. sensitive system components contr valv actuat more protectors contaminants generated from the pump.

3. **Return Side Filter:** Located between the control valve and the fluid reservoir; these filters are designed to capture debris from the working hydraulic systems components before returning the fluid back to the reservoir

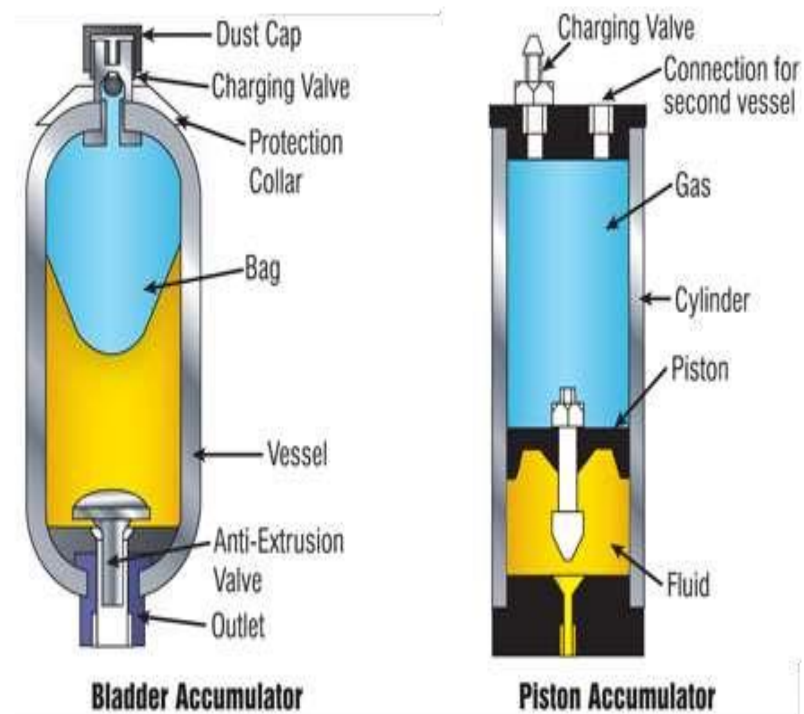
4.Offline Filter: These filters are used, independent from the hydraulic system, to clean hydraulic fluid before it enters the hydraulic system itself.





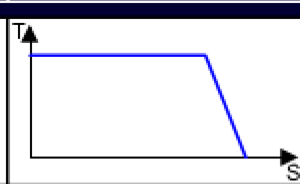
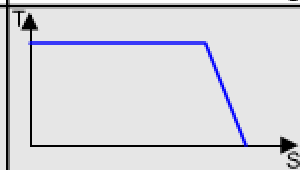
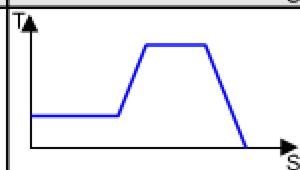
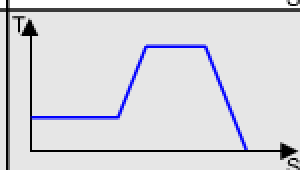
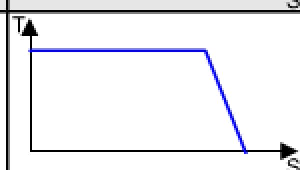
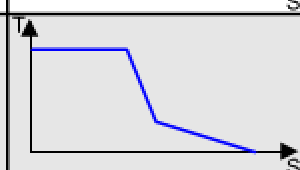
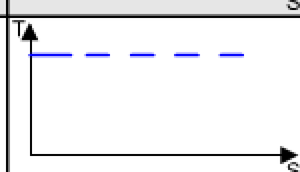
VII. ACCUMULATORS

- Unlike gases, the fluids used in hydraulic systems cannot be compressed and stored to cater to sudden demands of high flow rates that cannot be supplied by the pump.
- An accumulator in a hydraulic system provides means to store these incompressible fluids under pressure created either by a spring, or a compressed gas.
- Any tendency for pressure to drop at the inlet causes the spring or the gas to force the fluid back out, supplying the demand.



APPLICATIONS OF HYDRAULIC SYSTEMS

- applications, automated production lines, machine tool industries, paper industries, loaders, crushes, textile machineries, R & D equipment and robotic systems etc.
- **Mobile hydraulics:** Tractors, irrigation system, earthmoving equipment, material handling equipment, commercial vehicles, tunnel boring equipment, rail equipment, building and construction machineries and drilling rigs etc.
- **Automobiles:** It is used in the systems like breaks, shock absorbers, steering system, wind shield, lift and cleaning etc.
- **Industrial:** Plastic processing machineries, steel making and primary metal extraction
- **Marine applications:** It mostly covers ocean going vessels,

Motor type	Torque vs Speed	dedicated Applications	Effective Applications	Trend Applications	Advantages/ Disadvantages
Brush DC Motor		Industrial constant speed appls. Traction	Automotive	Automotive specific apps	Low cost well-tried technolog complex brushs
Universal Motor		Power tools vacuum cleaners washing machine food processor	Home appliance	—	Low cost well-tried technolog complex brushs
Asynchronous Motor (Induction) 3-Phase		heating, ventilation, air conditioning Washing machines	Blowers, fans, pumps industrial control	Robotics high-end industrial control	Robust, brushless, silent, reliable Low starting torque complex to commar
Asynchronous Motor (Induction) Single-Phase		Fans, water pumps	Industrial	—	Simple, Low cost, robust, brushless Low starting torque
Synchronous Motor Brushless DC Motor		Constant speed, high power, PFC	High tech Industrial constant speed appls: Traction/elevator Hard disk/CD drives	Entering the industrial domain through specific automotive	Brushless Simple electronic command Higher Cost
Switched Reluctance Motor		Traction industrial/automotive	—	Automotive Washing machine	Brushless, robust low cost electronic complex command
Stepper Motor		Printers/ Hard disk	Air conditioning louver Factory automation Machine tools	Automotive specific apps	High torque at rest position accuracy electronic complex command

Motor Control

Determining the operating point:

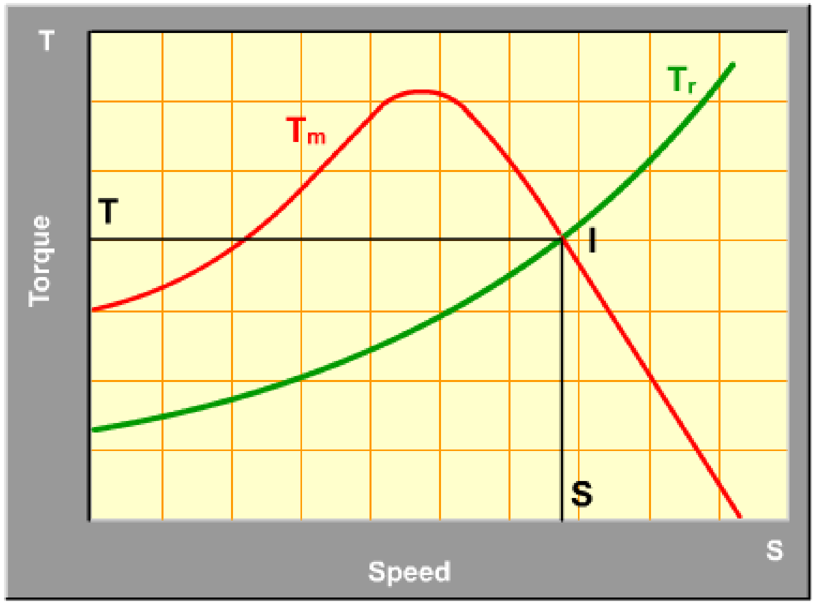
For medium and high power machines, the variation in speed and torque correspond to much greater time constants than those which control the current and voltage variation of the motor. Regarding the relationship between the motor and its load, it can be considered that operation is always at steady state, with transient operation considered as a succession of steady state operations.

The mechanical characteristic of a motor supplied at constant voltage and frequency is the curve giving, for the different possible operating modes, the motor torque developped T_m according to speed **S**.

The mechanical characteristic of the driven load give the resistive torque T_r according to the drive speed.

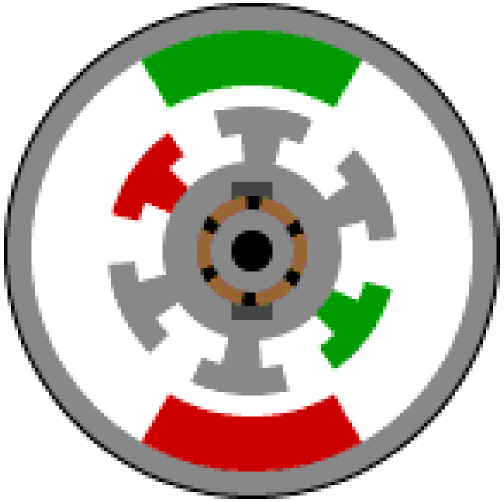
The speed and the torque are given by the intersection' point of the 2 characteristics.

At zero speed ,T_m must be greater than T_r for the machine to start. The increase in speed depends on the inertia of the motor and load and the accelerating torque T_m-T_r. The speed stabilises when T_m-T_r equals zero, hence at the point of intersection of the 2 characteristics. **Point I is stable**. If S increases, T_m is less than T_r: the motor slow down. In the same way If S decreases: the motor will accelerate



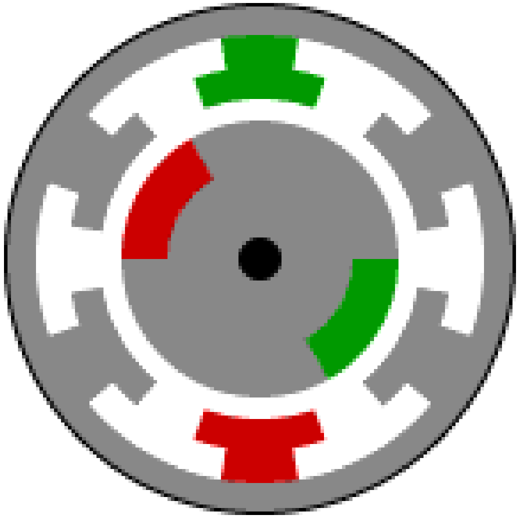
DC Motors

https://www.youtube.com/watch?v=LAtPHANEfQo&list=PPSV



- The stator is the stationary outside part of a motor. The rotor is the inner part which rotates.
- Just as the rotor reaches alignment, the brushes move across the commutator contacts and energize the next winding
- The brushes of a dc motor have several limitations; brush life, brush residue, maximum speed, and electrical noise

Brushless DC Motors



- A brushless dc motor has a rotor with permanent magnets and a stator with windings. It is essentially a dc motor turned inside out. The control electronics replace the function of the commutator and energize the proper winding.

Motor Control

Precise positioning

The only way to effectively use a DC motor for precise positioning is to use a *servo. Servo* usually implement a small DC motor, a feedback mechanism (usually a potentiometer, a resolver or an optical sensor with attached to the shaft by gearing or other means), and a control circuit which compares the position of the motor with the desired position, and moves the motor accordingly.

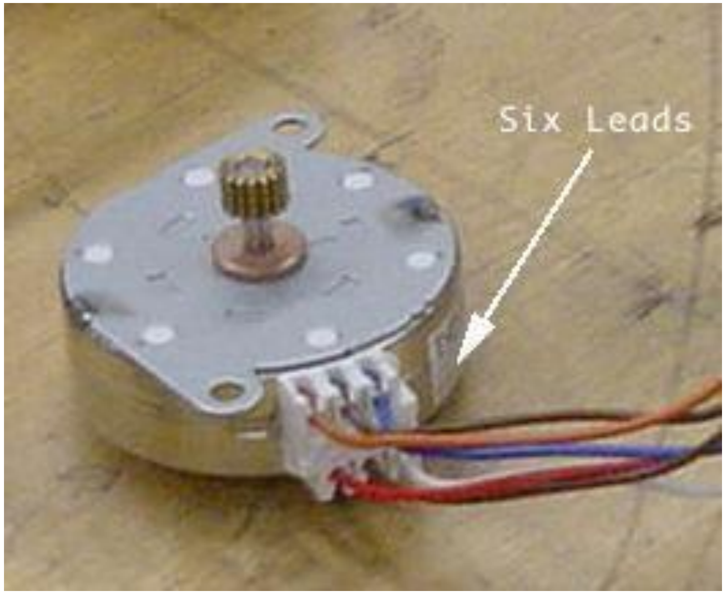
Stepper motors, however, behave differently than standard DC motors. First of all, they cannot run freely by themselves. Stepper motors do as their name suggests - they "step" a little bit at a time.

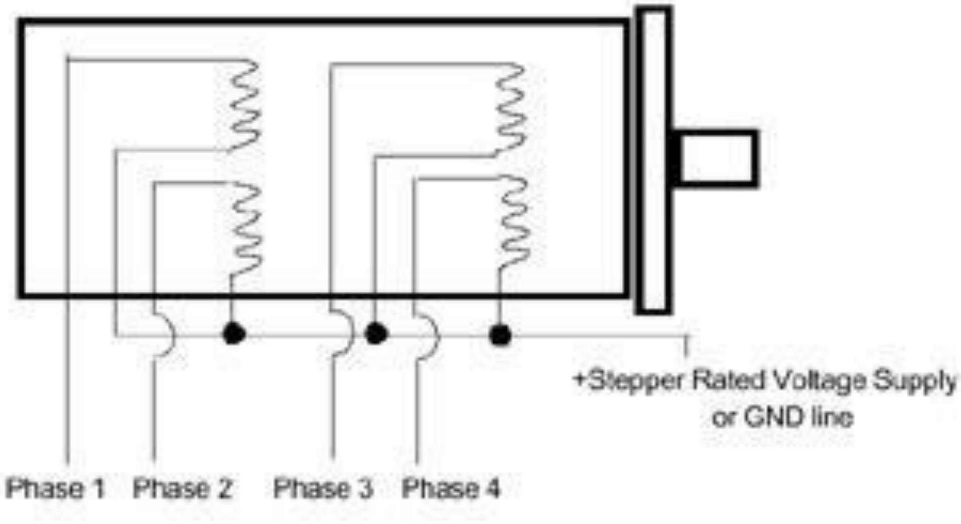
Stepper motors produce the highest torque at low speeds. Stepper motors also have another characteristic "Detente torque" allowing a stepper motor to hold its position firmly when not turning. This eliminates the need for a mechanical break mechanism.

Stepper motors have several windings which need to be energized in the correct sequence, converting digital pulse inputs to incremental shaft rotation. The rotation not only has a direct relation to the number of input pulses, but its speed is related to the frequency of the pulses.

Stepper Motors

- A stepper motor is similar to a conventional motor but has the added ability to rotate through a fixed amount of degrees for every voltage pulse it experiences.
- This ability allows the stepper motor to move between two fixed points very accurately.
- Figure 1, in the next slide, is a picture of a typical stepper motor. Notice there are six leads instead of the usual two. The extra wires are needed because there are multiple coils in the motor casing, which allow the motor to "step" a fraction of a rotation.
- Figure 2 shows the schematic for the stepper motor. Pulsing the coils, or phases, sequentially will cause the motor to rotate clockwise or counter-clockwise depending on the sequence chosen. The speed of rotation is determined by the frequency of the pulses to the coils.





Motor Schematic

Stepper Motor

https://www.youtube.com/watch?v=VfqYN1eG9Zk

a) Stepping motors are electromagnetic, rotary, incremental devices which convert digital pulses into mechanical rotation. The amount of rotation is directly proportional to the number of pulses and the speed of rotation is relative to the frequency of those pulses.

Stepping motors are simple to drive in an open loop configuration and for their size provide excellent torque at low speed.

The benefits offered by stepping motors include:

a) a simple and cost effective design
b) high reliability
c) maintenance free (no brushes)
d) open loop (no feed back device required)
e) known limit to the 'dynamic position error'

a)

a) Although various types of stepping motor have been developed, they all fall into three basic categories.

a) variable reluctance (V.R)
b) permanent magnet (tin can)
c) hybrid

The **variable reluctance** or **V.R.** (fig 1) motor consist of a rotor and stator each with a different number of teeth. As the rotor does not have a permanent magnet it spins freely i.e. it has no detent torque. Although the torque to inertia ratio is good, the rated torque for a given frame size is restricted. Therefore small frame sizes are generally used and then very seldom for industrial applications.

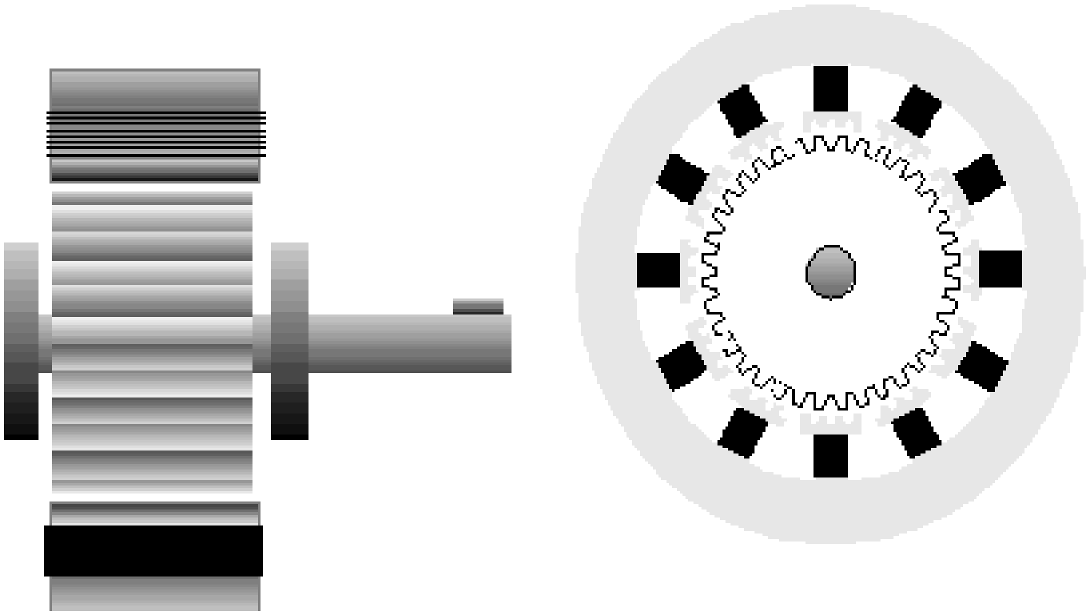


Figure 1. cross section through a variable reluctance stepping motor

The **permanent magnet** (PM) or **tin can** (fig. 2) motor is perhaps the most widely used stepping motor in non-industrial applications. In it's simplest form the motor consists of a radially magnetized permanent magnet rotor and a stator similar to the **V.R.** motor. Due to the manufacturing techniques used in constructing the stator they are also sometimes known as **'claw pole'** motors.

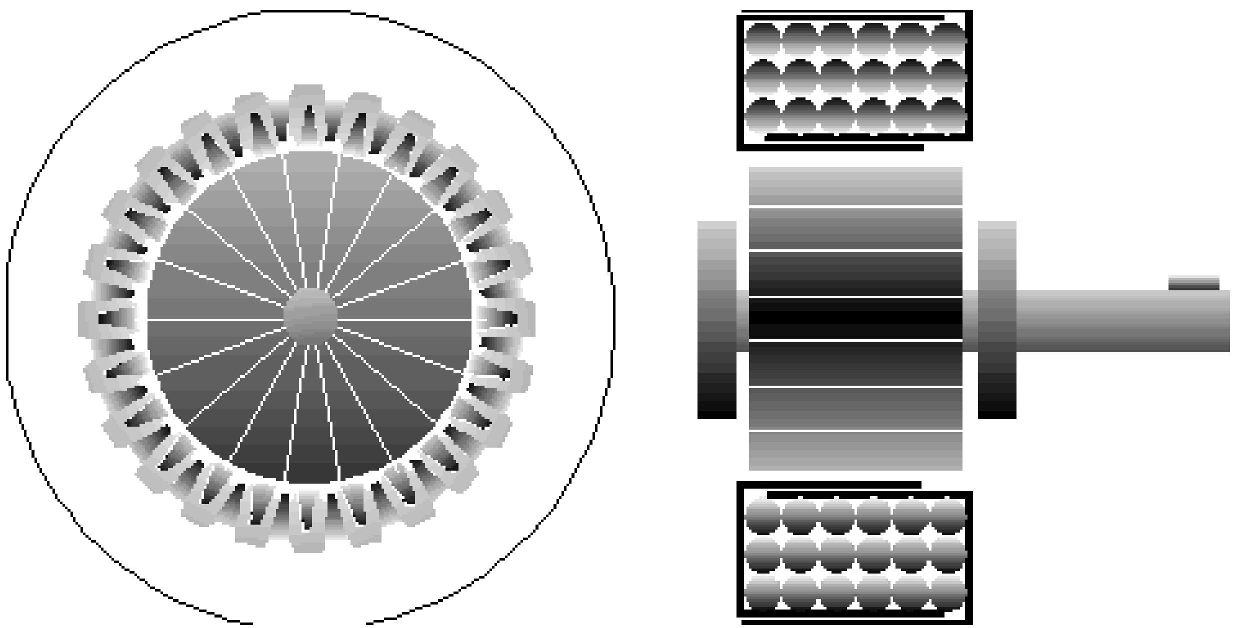


Figure 2. cross section through a permanent magnet

Examples

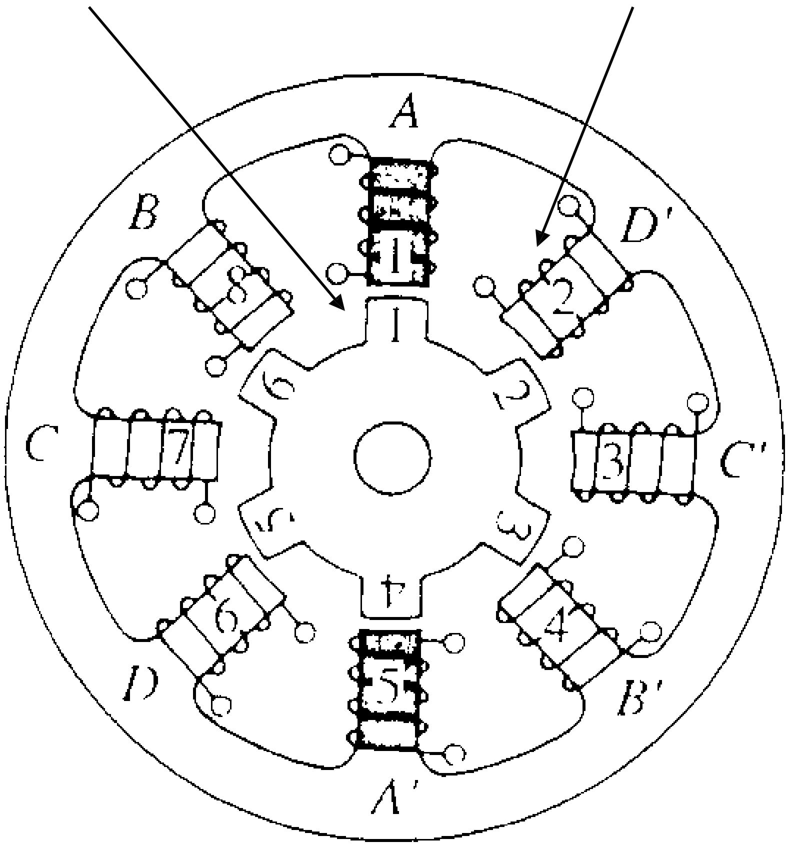
a) There are many times when fixed amounts of rotation are needed instead of continuous rotation.
b) One example is a printer. In order to print text and graphics, the printer needs to know where the printer head is in relation to the frame and how much paper has been fed into the printer. Using a stepper motor allows this information to be known, because the printer can keep track of how many pulses it has sent to the stepper motors.
c) If the printer has an algorithm telling it how far the printer head moves with one pulse, then the exact position of the printer head is known, assuming there is not a malfunction in the motor.
d) This is also true for the paper feed.
e) Other examples of stepper motor use are robotic arms, hard disk drives and clocks. All of these things require precise movement or require knowledge of the exact location of the rotating equipment.

Stepper Motors

- A stepper motor is a "pulse-driven" motor that changes the angular position of the rotor in "steps"
- Define
  - β = the step angle (per input pulse)
  - Resolution = the number of steps/revolution
  - θ = total angle traveled by the rotor
    - = β X # of steps
  - n = the shaft speed = $(\beta \text{ X } f_p) / 360°$
    - f_p = # of pulses/second

Variable-Reluctance Stepper Motor

Toothed Rotor and Toothed Stator



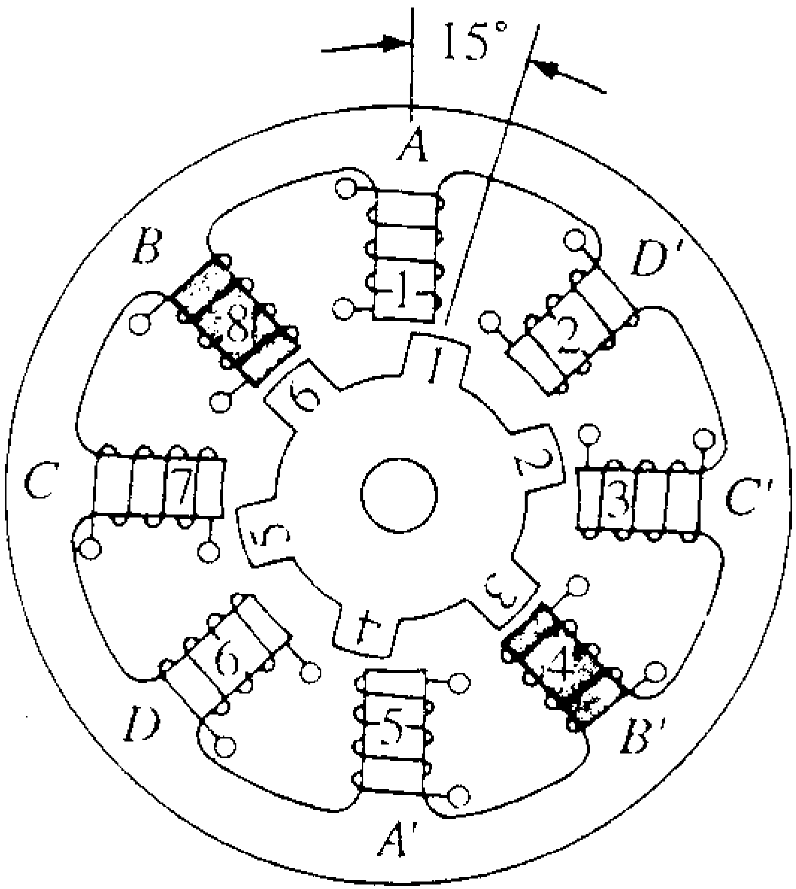
Principle of Operation:

Reluctance of the magnetic circuit formed by the rotor and stator teeth varies with the angular position of the rotor

Here, energize coils A and A’ (Phase A)

Rotor “steps” to align rotor teeth 1 and 4 with stator teeth 1 and 5

Variable-Reluctance Stepper Motor



Energize coils B and B' (Phase B)

Rotor steps "forward"

Rotor teeth 3 and 6 align with Stator teeth 1 and 5

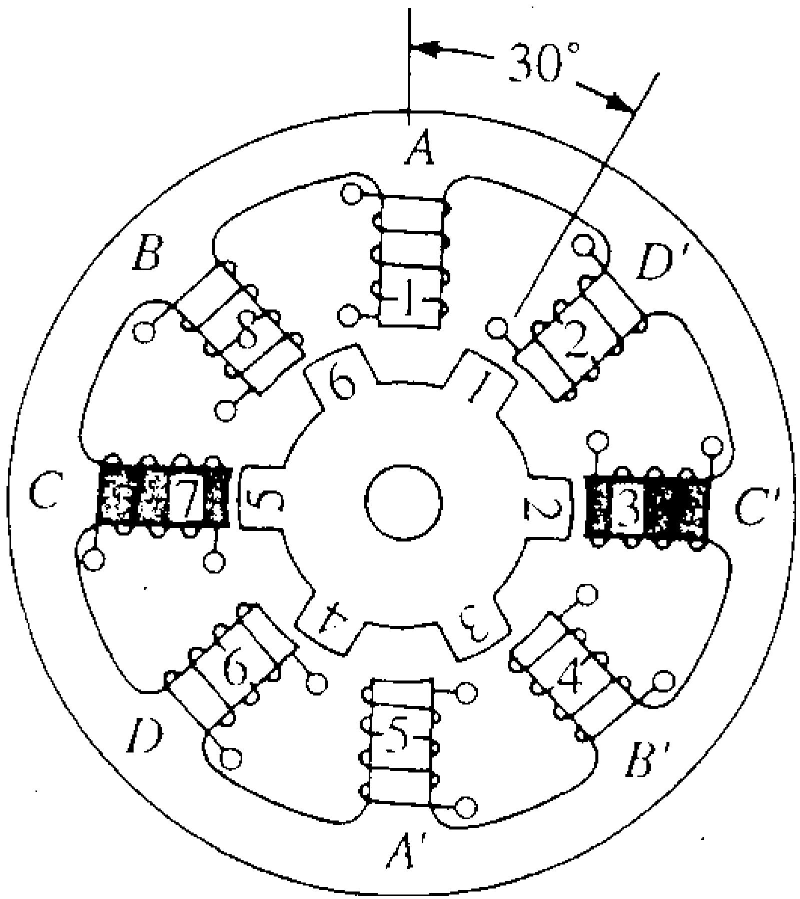
Let N_s = # of teeth on the stator

N_r = # of teeth on the rotor

β = Step Angle in space degrees

$$\beta = \frac{|N_s - N_r|}{N_s \cdot N_r} \times 360°$$

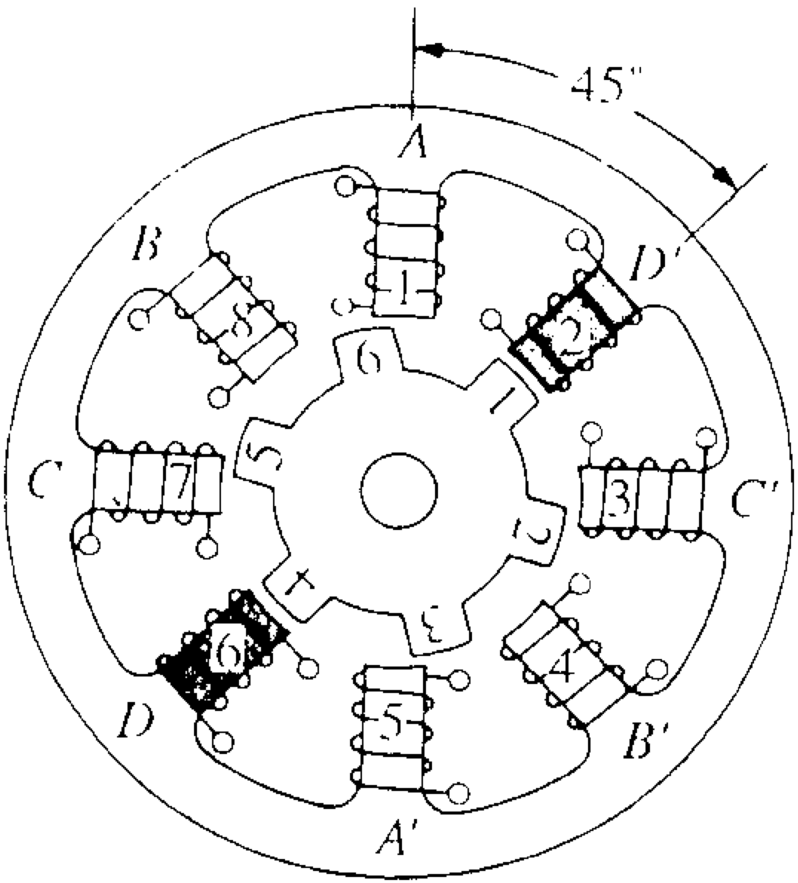
Variable-Reluctance Stepper Motor



Energize Phase C

Rotor steps forward another 15°

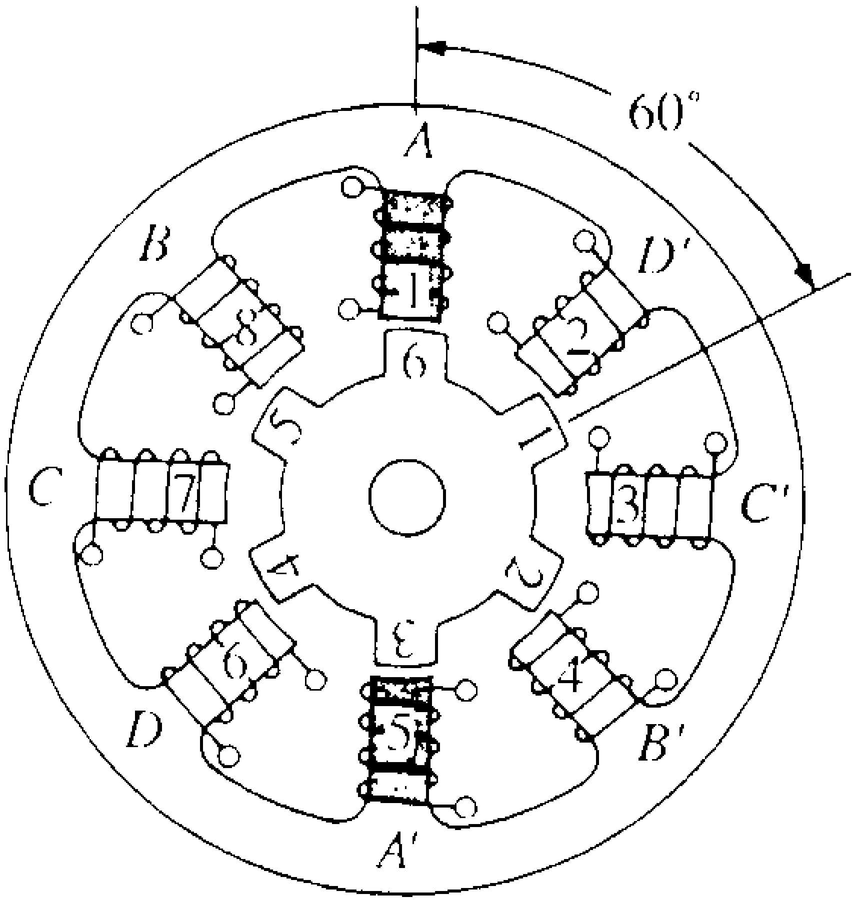
Variable-Reluctance Stepper Motor



Energize Phase D

Rotor steps forward another 15°

Variable-Reluctance Stepper Motor



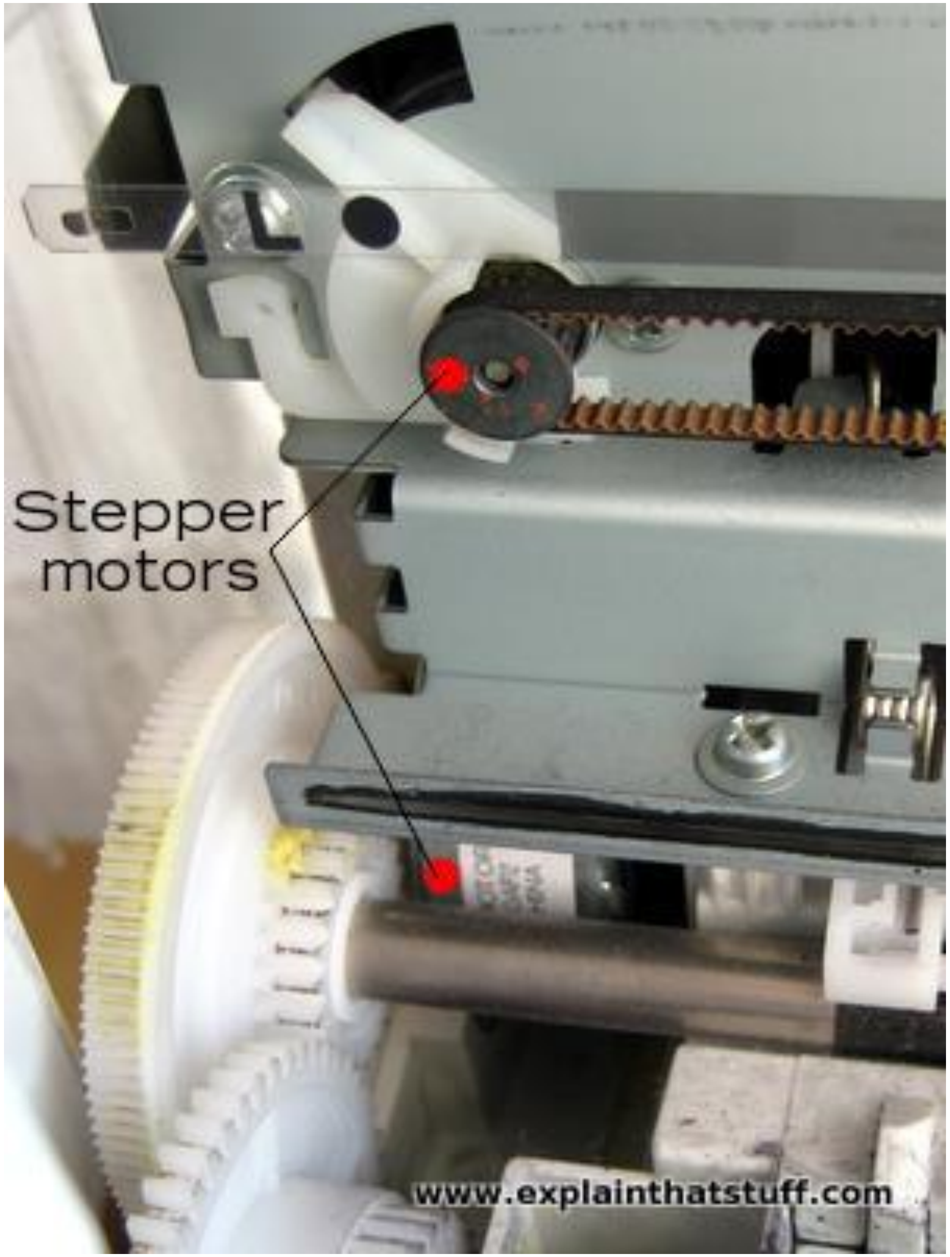
Repeat the sequence

Energize Phase A

Rotor steps forward again


www.explainthatstuff.com


1
2
3
4
5
6
www.explainthatstuff.com


Stepper
motors
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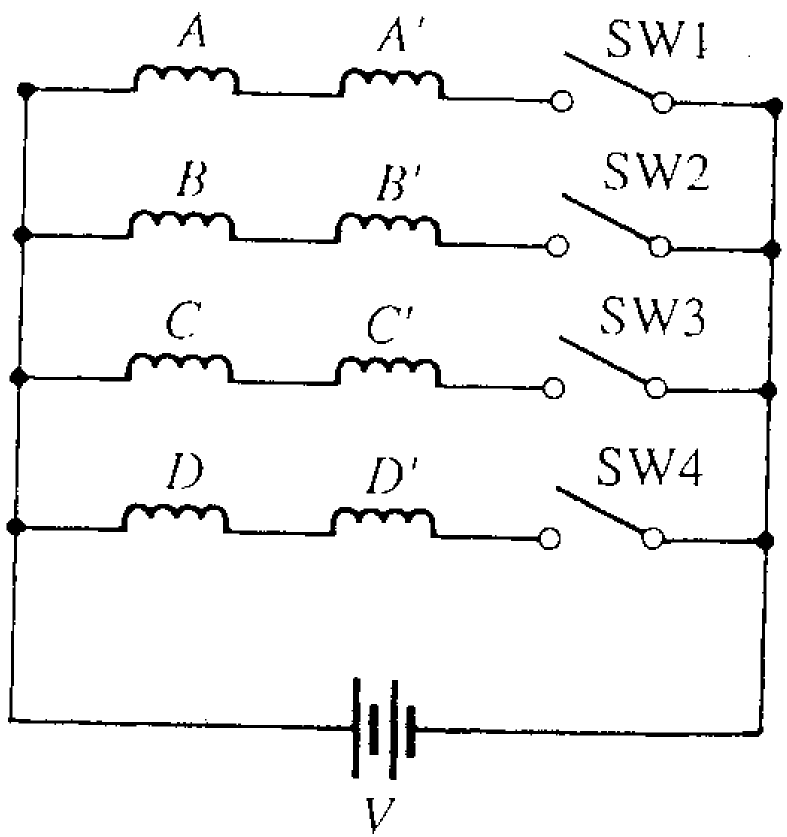
Variable-Reluctance Stepper Motor

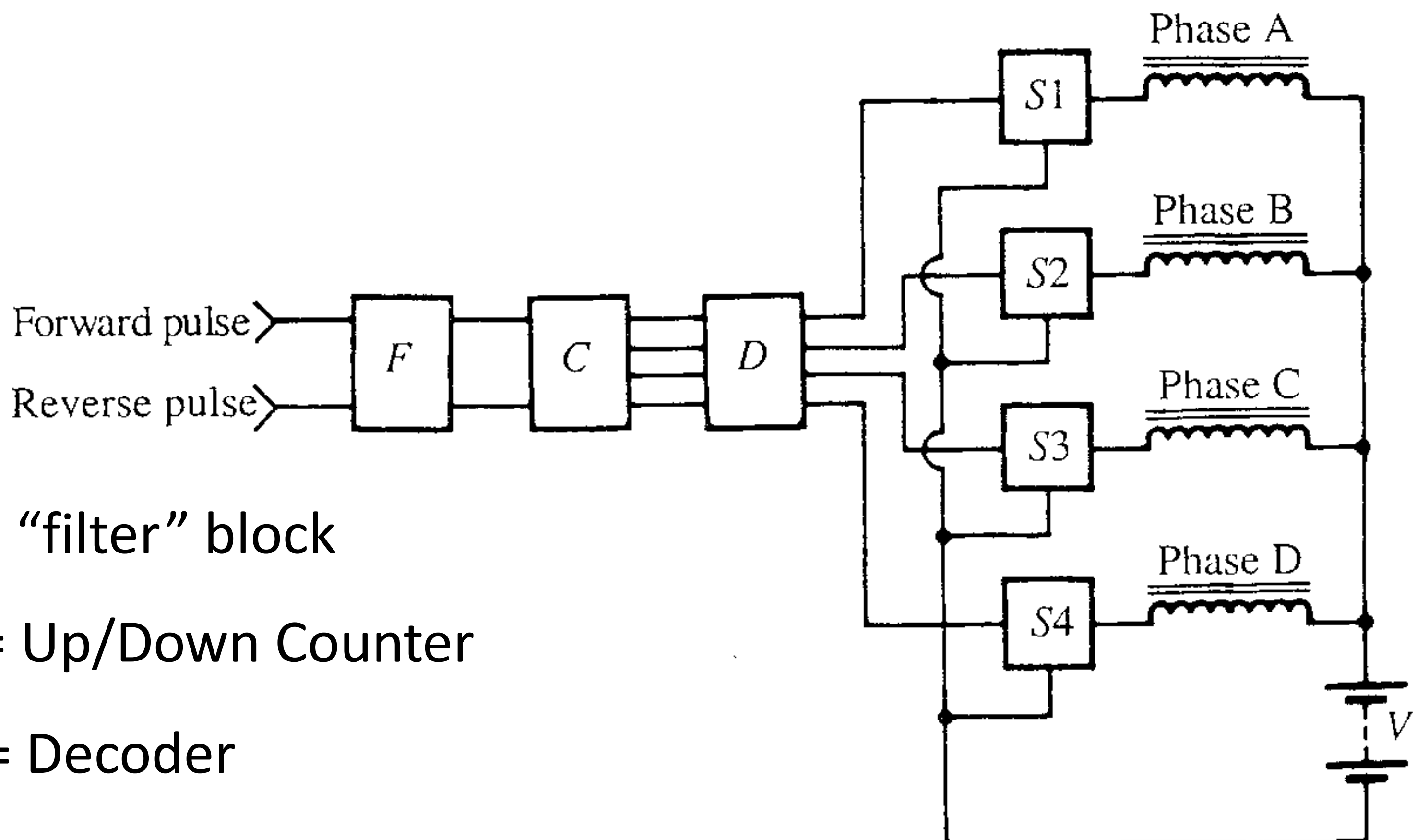


Switching Circuit for the stepper motor

Close switches in order 1, 2, 3, and 4 to turn the rotor "clockwise"

Close switches in reverse order - 4, 3, 2, and 1 to change rotation to the opposite (counter-clockwise) direction

Variable-Reluctance Stepper Motor Typical Driver Circuit



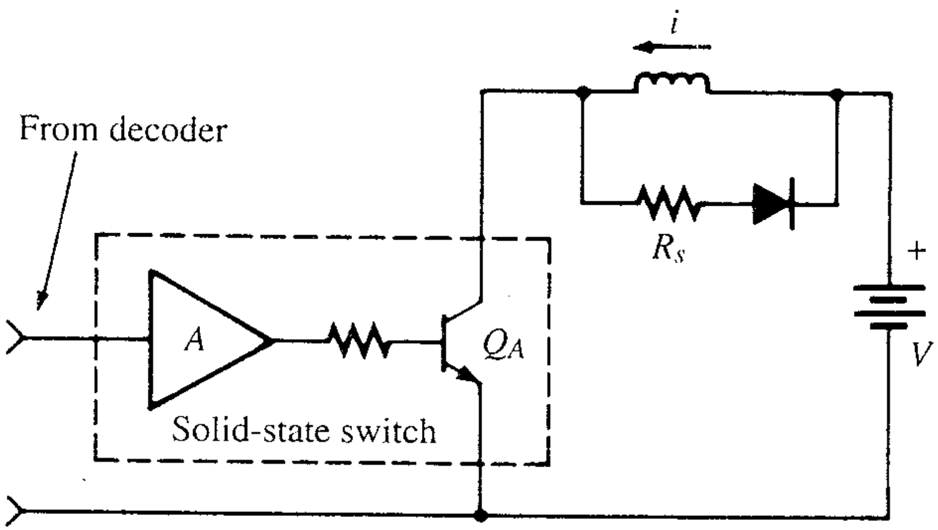
F = “filter” block

C = Up/Down Counter

D = Decoder

S = Electronic Switch (transistor)

Typical Switching Circuit



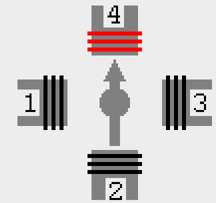
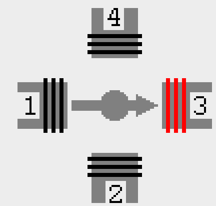
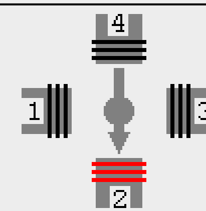
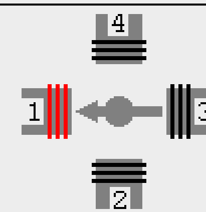
Decoder provides logic output to turn Q_A On/Off

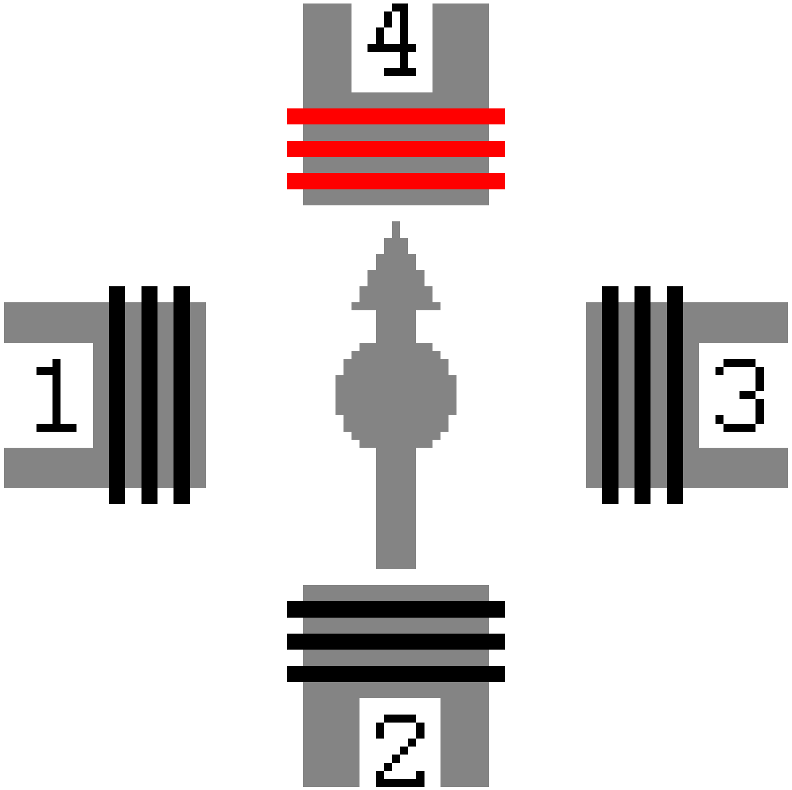
Amplifier A “conditions” the logic pulses

When Q_A turns On, it conducts current in the motor phase A winding

When Q_A turns Off, D and R_S conduct current to “discharge” the phase winding

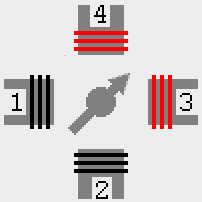
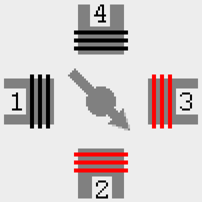
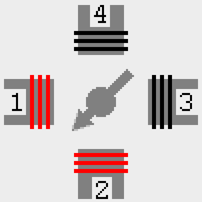
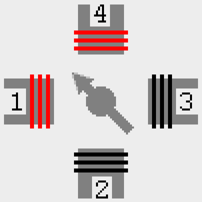
. **Single-Coil Excitation** - Each successive coil is energized in turn.

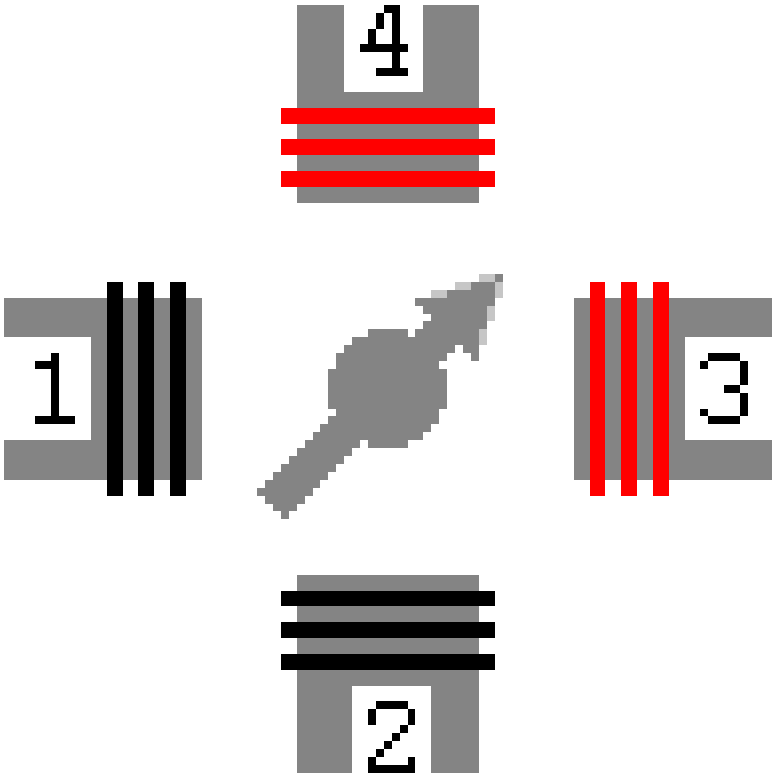
Step	Coil 4	Coil 3	Coil 2	Coil 1	
a.1	on	off	off	off	
a.2	off	on	off	off	
a.3	off	off	on	off	
a.4	off	off	off	on	



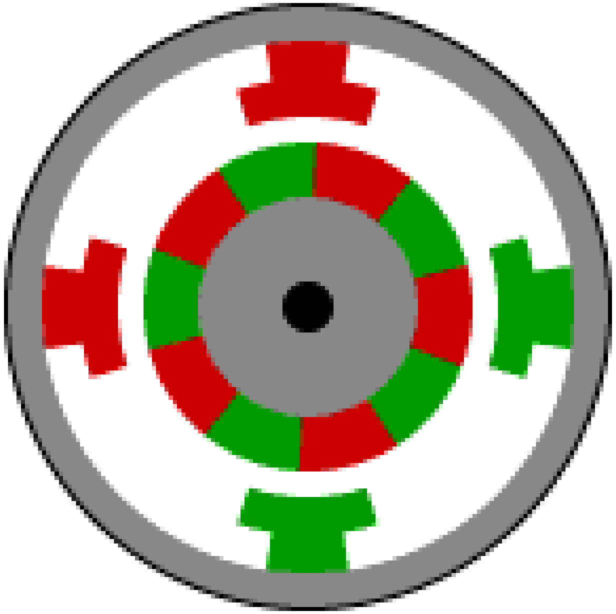
4
1
3
2

Two-Coil Excitation - Each successive pair of adjacent coils is energised in turn.

Step	Coil 4	Coil 3	Coil 2	Coil 1	
b.1	**on**	**on**	off	off	
b.2	off	**on**	**on**	off	
b.3	off	off	**on**	**on**	
b.4	**on**	off	off	**on**	

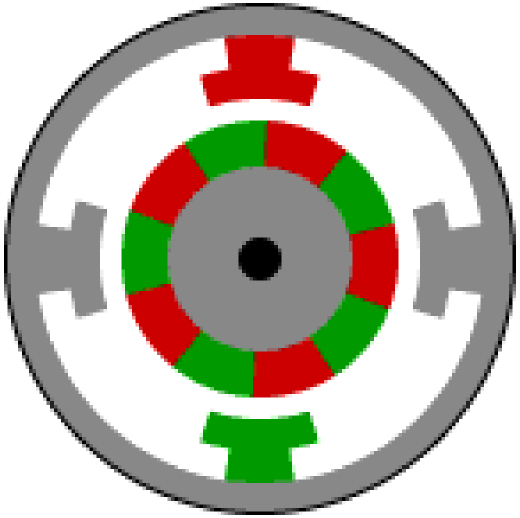

4
1
3
2

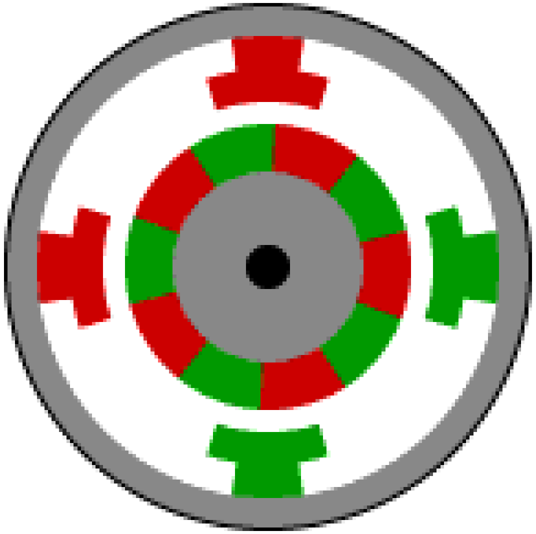
Half Stepper Motor



- This animation shows the stepping pattern for a half-step stepper motor. The commutation sequence for a half-step stepper motor has eight steps instead of four. The main difference is that the second phase is turned on before the first phase is turned off. Thus, sometimes both phases are energized at the same time. During the half-steps the rotor is held in between the two full-step positions. A half-step motor has twice the resolution of a full step motor. It is very popular for this reason.

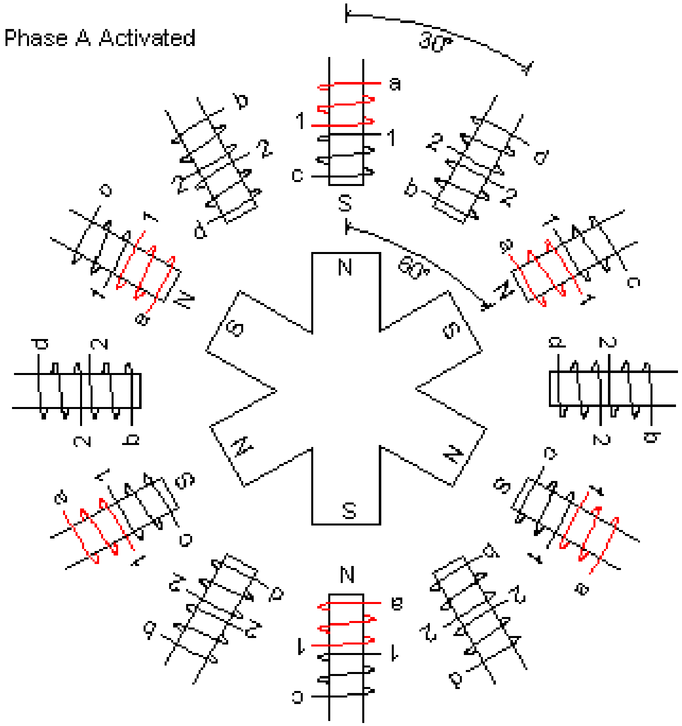
Stepper Motors

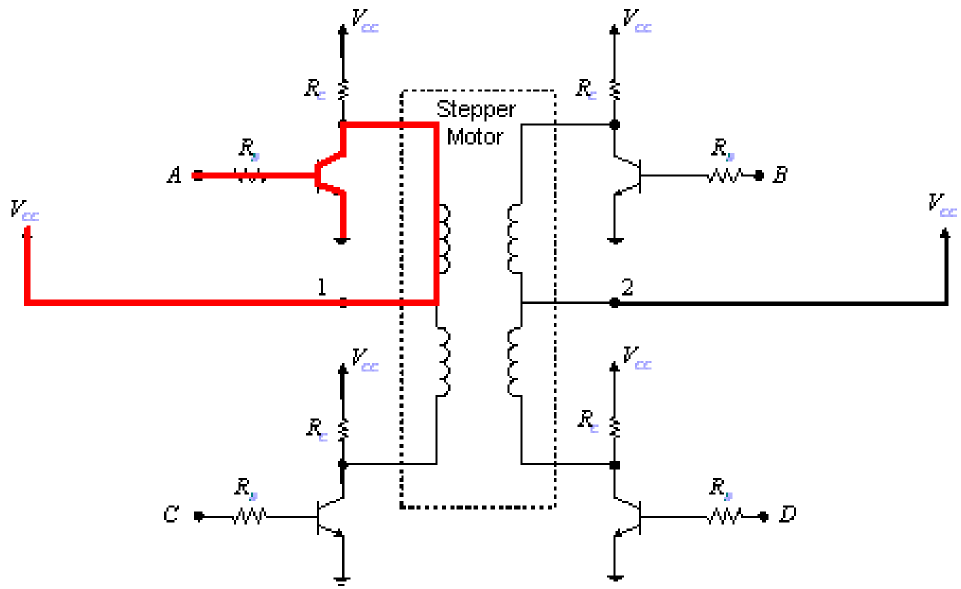




- Some stepper motor uses permanent magnets. Some stepper motors do not have magnets and instead use the basic principles of a switched reluctance motor. The stator is similar but the rotor is composed of a iron laminates.

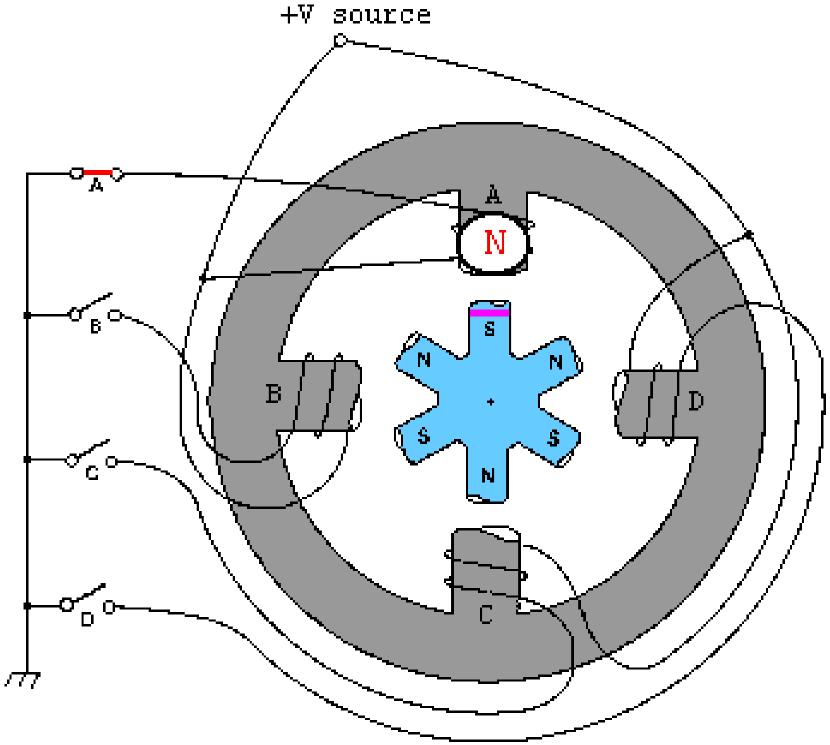
Half Stepping





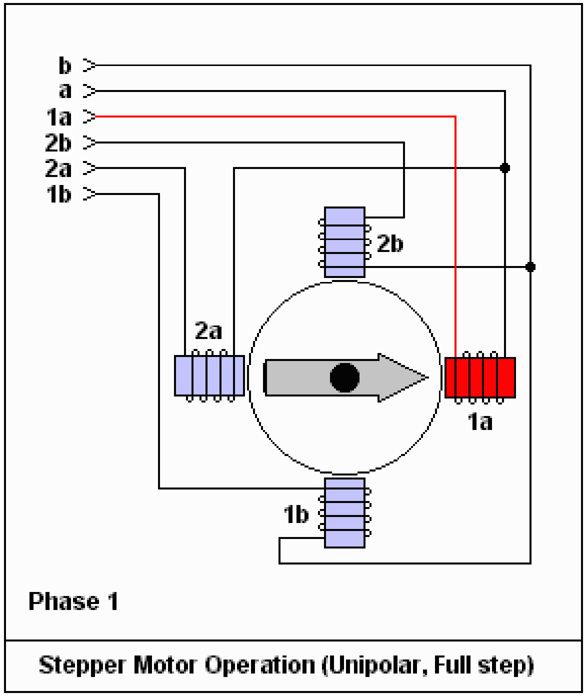
- Note how the phases are driven so that the rotor takes half steps

Full Stepping



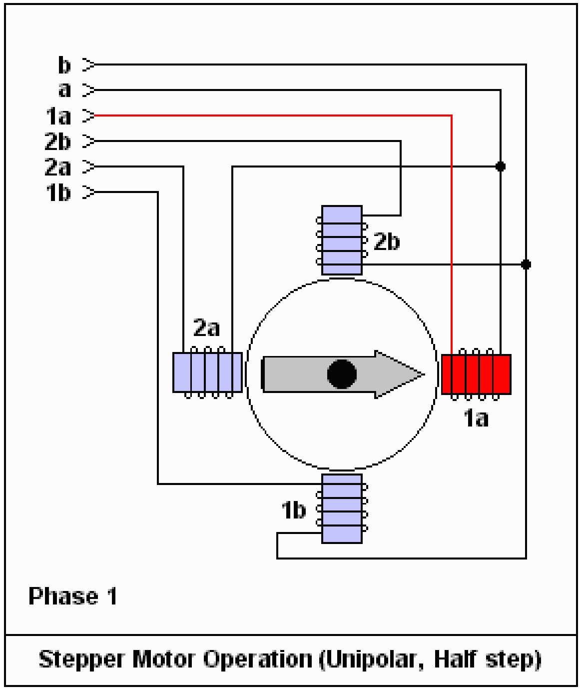
- Animation shows how coils are energized for full steps

Stepping Sequence



Clockwise Rotation

Index	1a	1b	2a	2b
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1
5	1	0	0	0
6	0	1	0	0
7	0	0	1	0
8	0	0	0	1



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Index	1a	1b	2a	2b
1	1	0	0	0
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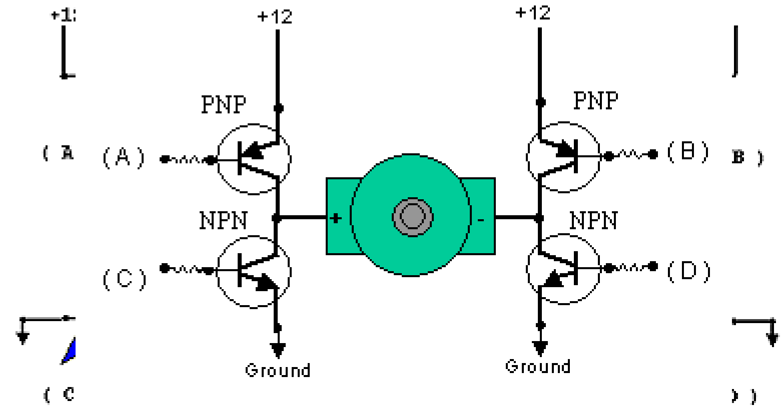
4	0	1	1	0
5	0	0	1	0
6	0	0	1	1
7	0	0	0	1
8	1	0	0	1
9	1	0	0	0
10	1	1	0	0
11	0	1	0	0
12	0	1	1	0
13	0	0	1	0
14	0	0	1	1
15	0	0	0	1
16	1	0	0	1

- Full step sequence showing how binary numbers can control the motor

- Half step sequence of binary control numbers

H-Bridge:

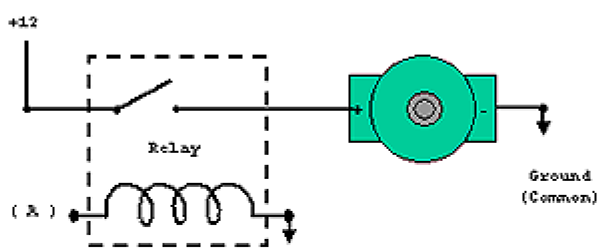
Enables you to control the motor in both forward and reverse with a microcontroller.

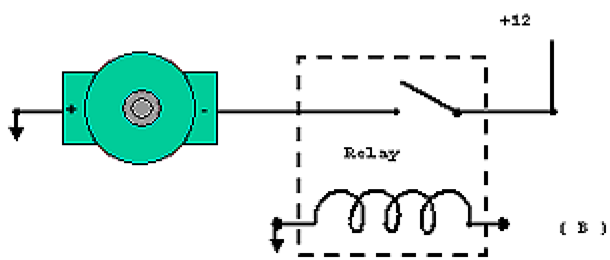


A	B	C	D	Function
1	0	0	1	Forward
0	1	1	0	Reverse
1	1	0	0	Brake
0	0	1	1	Brake
1	0	1	0	Fuse test :-)
0	1	0	1	Fuse test :-)

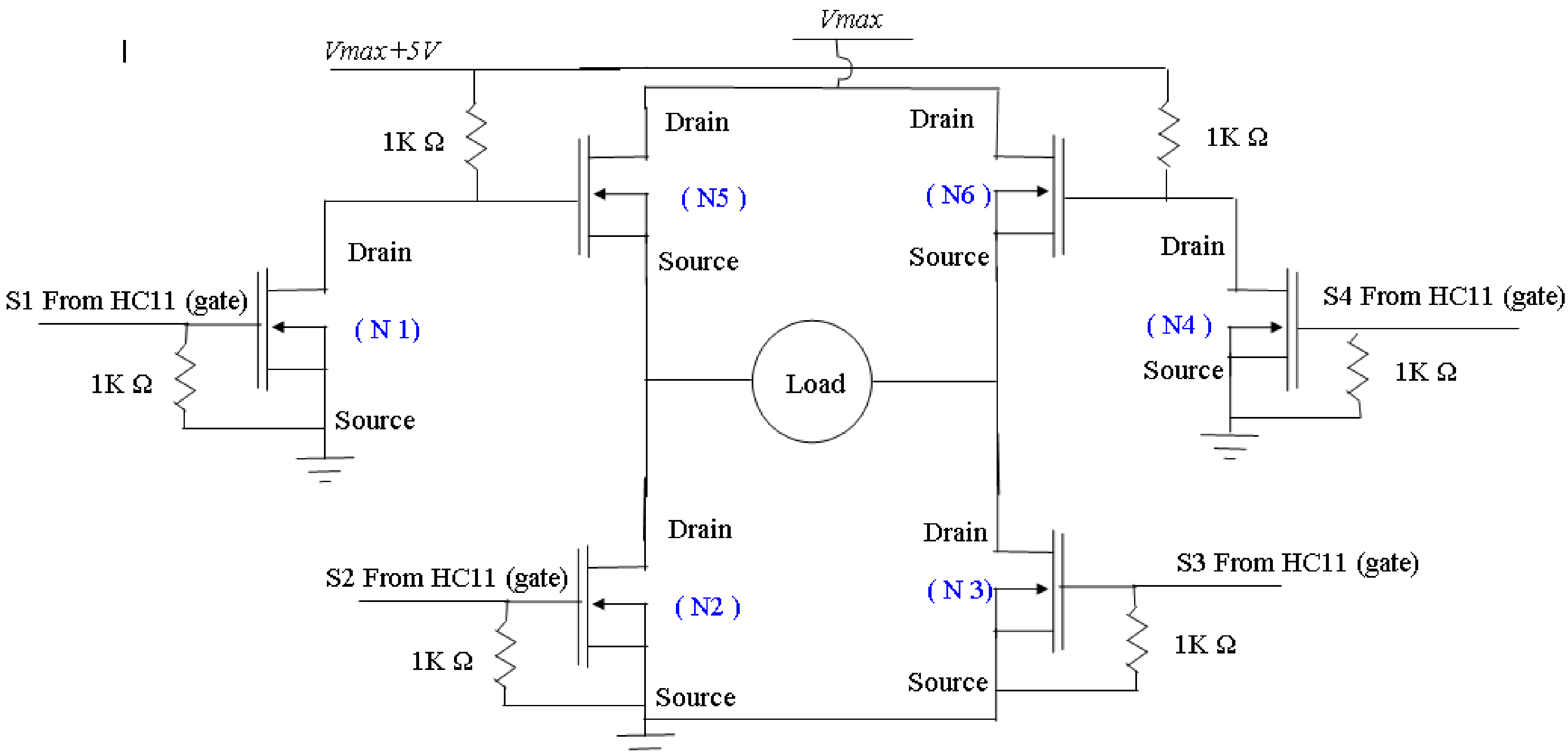
Don't do the fuse tests

A	Function
1	Forward
0	Stop (Coast)





B	Function
1	Reverse
0	Stop


Vmax
Vmax+5V
1K Ω
Drain
Drain
1K Ω
(N5)
(N6)
Drain
Source
Source
Drain
S1 From HC11 (gate)
(N 1)
S4 From HC11 (gate)
(N4)
Source
1K Ω
1K Ω
Load
Source
Drain
Drain
S2 From HC11 (gate)
(N2)
(N 3)
S3 From HC11 (gate)
1K Ω
1K Ω
Source
Source

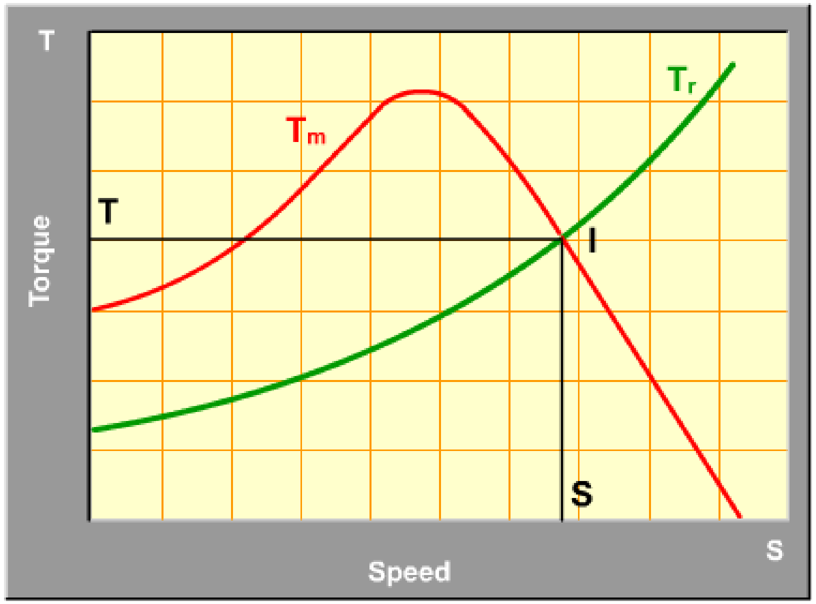
Motor Control

Determining the operating point:

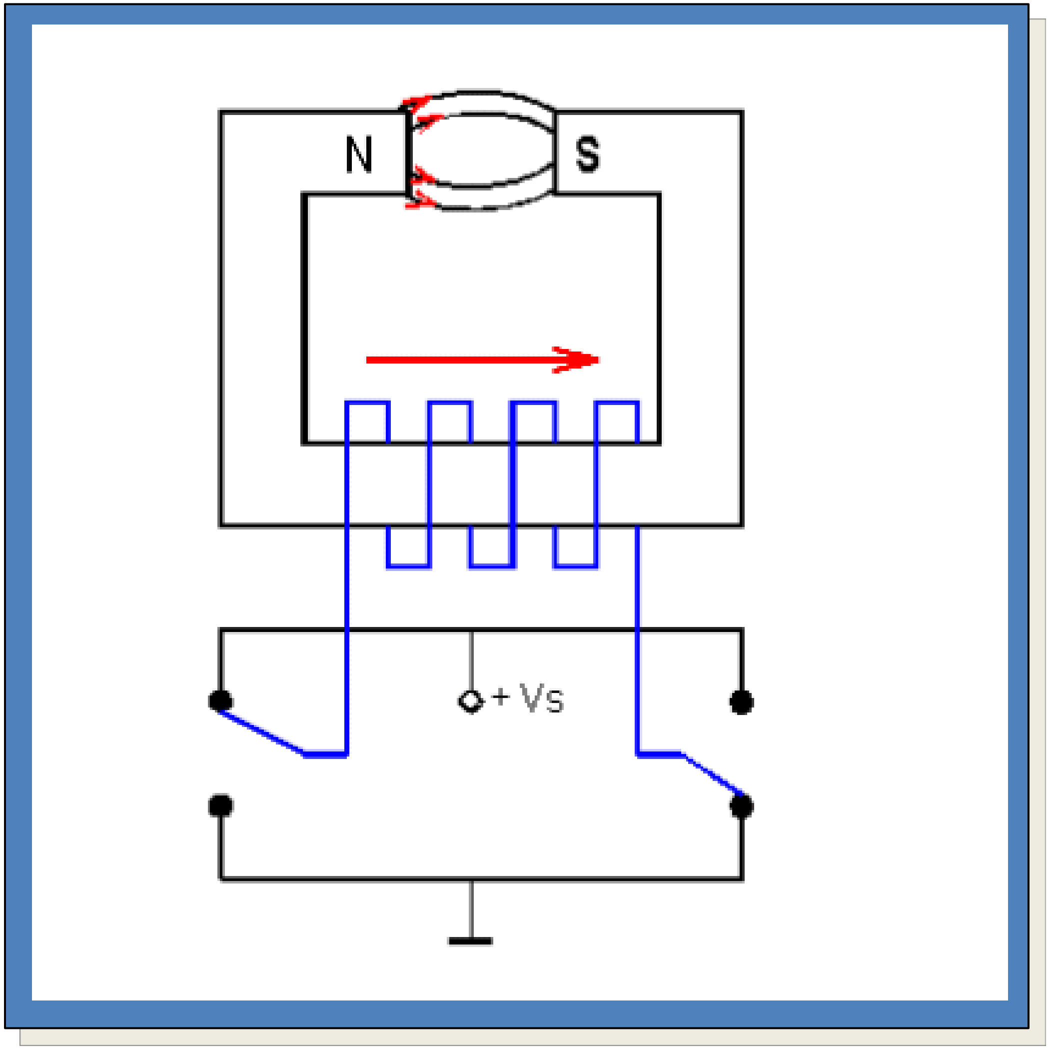
For medium and high power machines, the variation in speed and torque correspond to much greater time constants than those which control the current and voltage variation of the motor. Regarding the relationship between the motor and its load, it can be considered that operation is always at steady state, with transient operation considered as a succession of steady state operations.

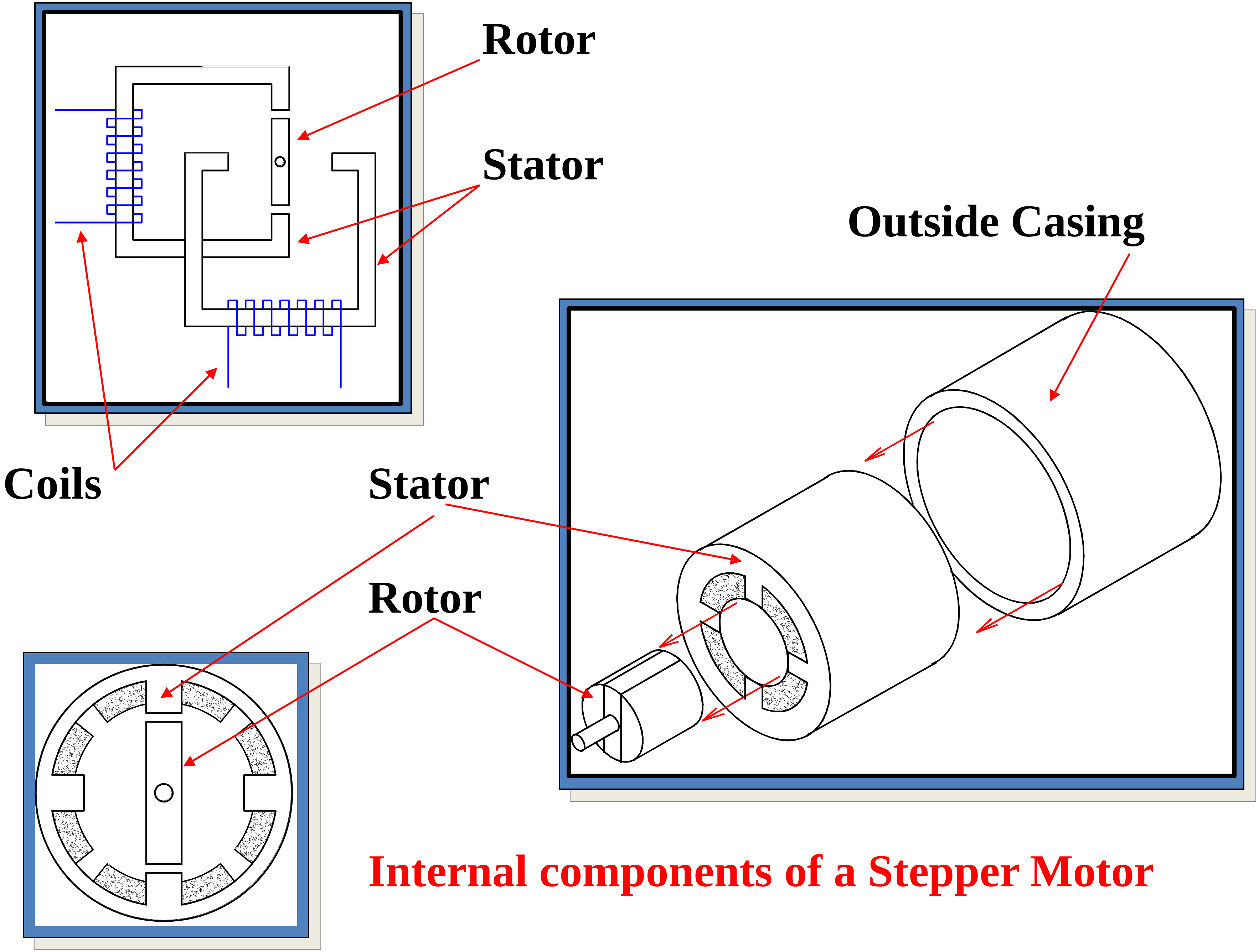
The mechanical characteristic of a motor supplied at constant voltage and frequency is the curve giving, for the different possible operating modes, the motor torque developped T_m according to speed **S**.
The mechanical characteristic of the driven load give the resistive torque T_r according to the drive speed.
The speed and the torque are given by the intersection' point of the 2 characteristics.

At zero speed ,T_m must be greater than T_r for the machine to start. The increase in speed depends on the inertia of the motor and load and the accelerating torque T_m-T_r. The speed stabilises when T_m-T_r equals zero, hence at the point of intersection of the 2 characteristics. **Point I is stable**. If S increases, T_m is less than T_r: the motor slow down. In the same way If S decreases: the motor will accelerate



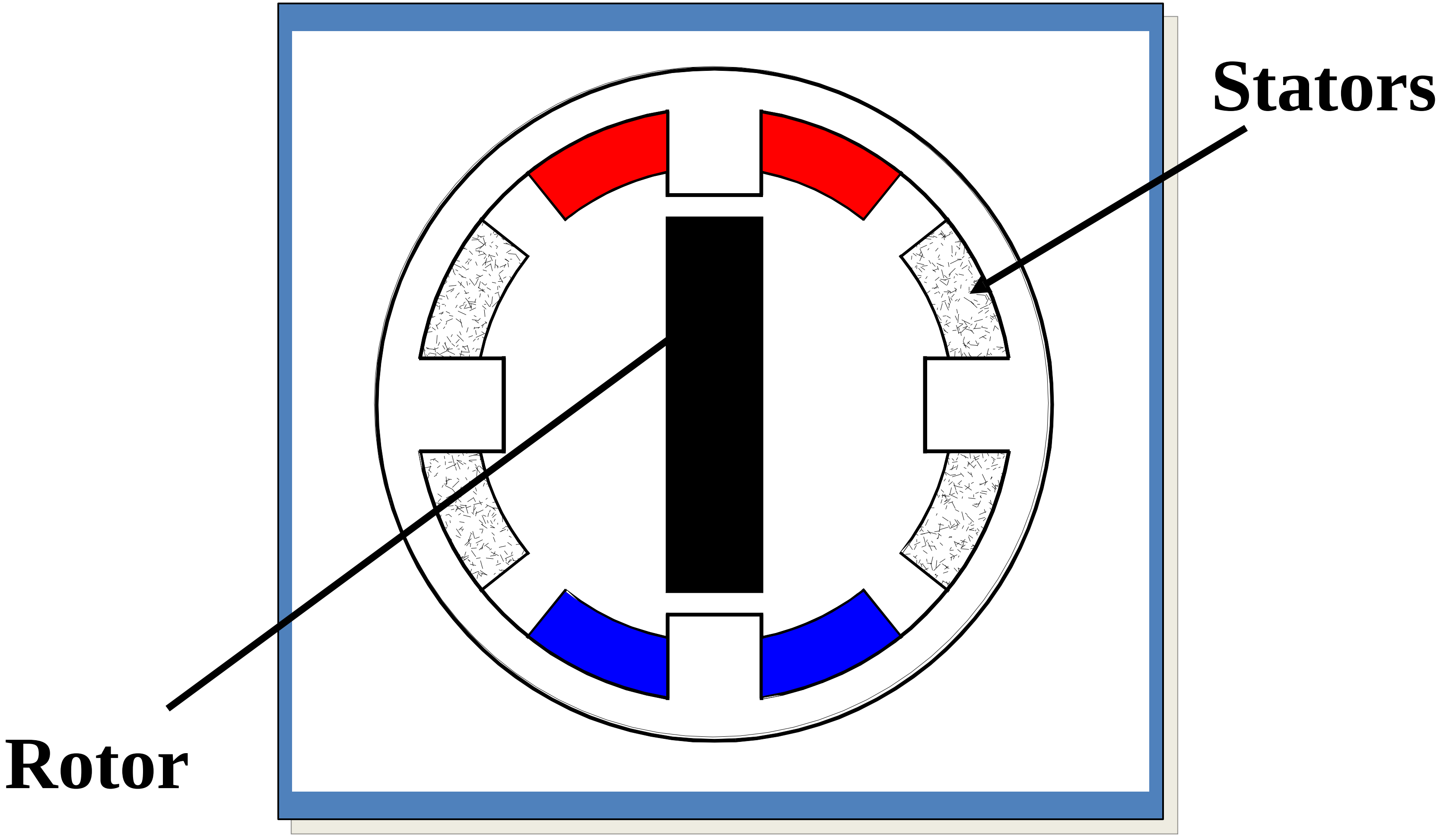
Stepper Motor / Electro magnet



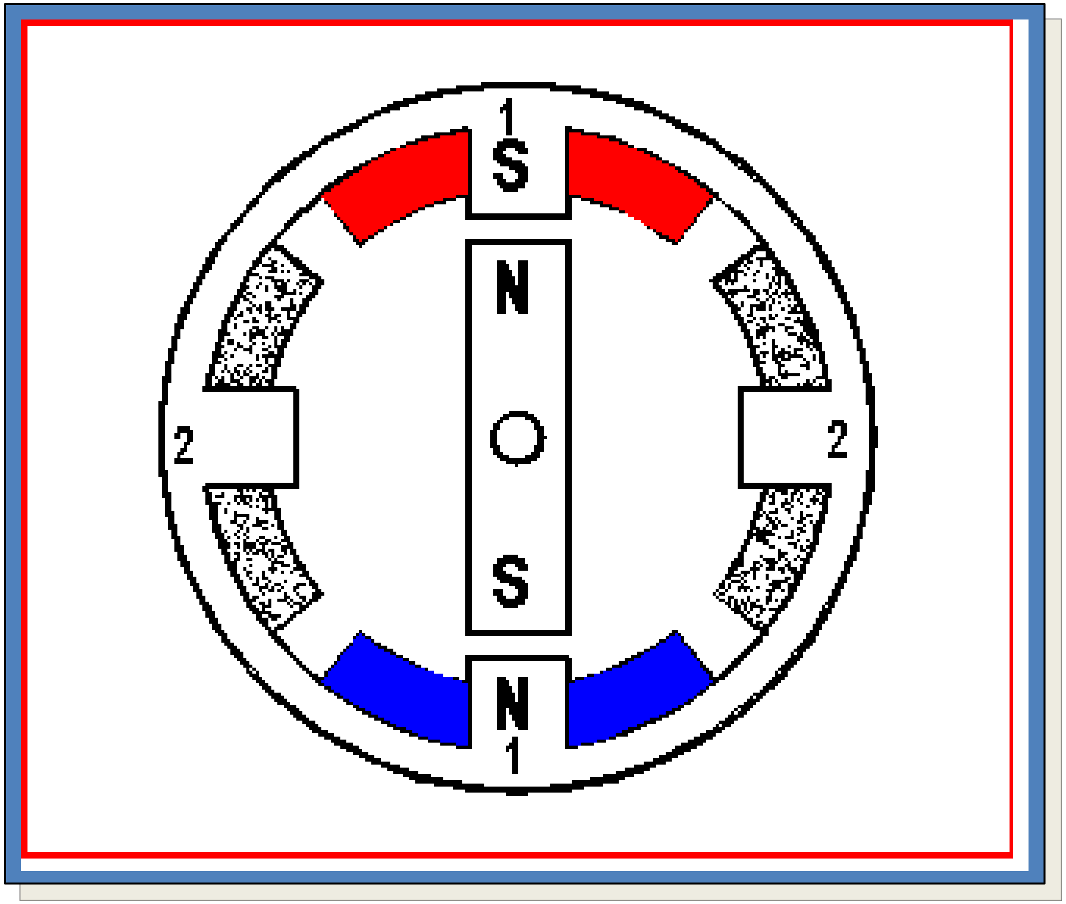


Internal components of a Stepper Motor

Cross Section of a Stepper Motor

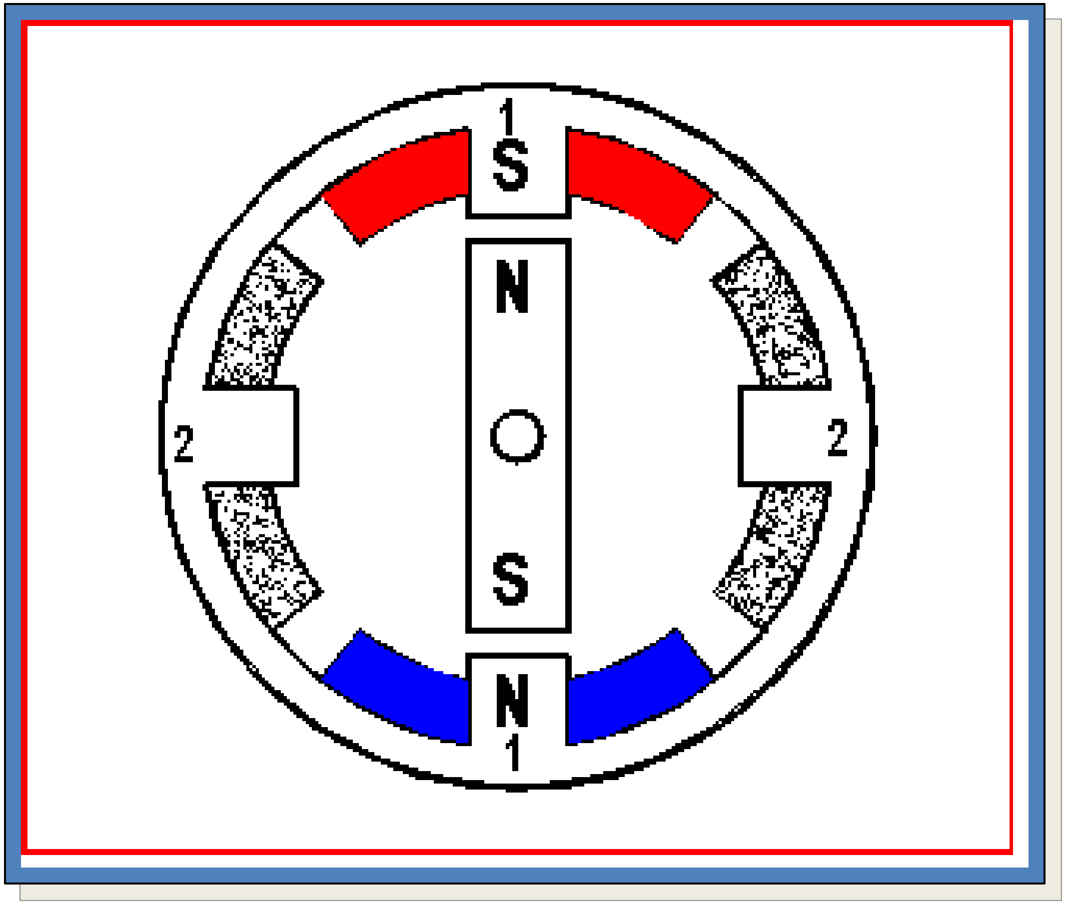


Full Step Operation

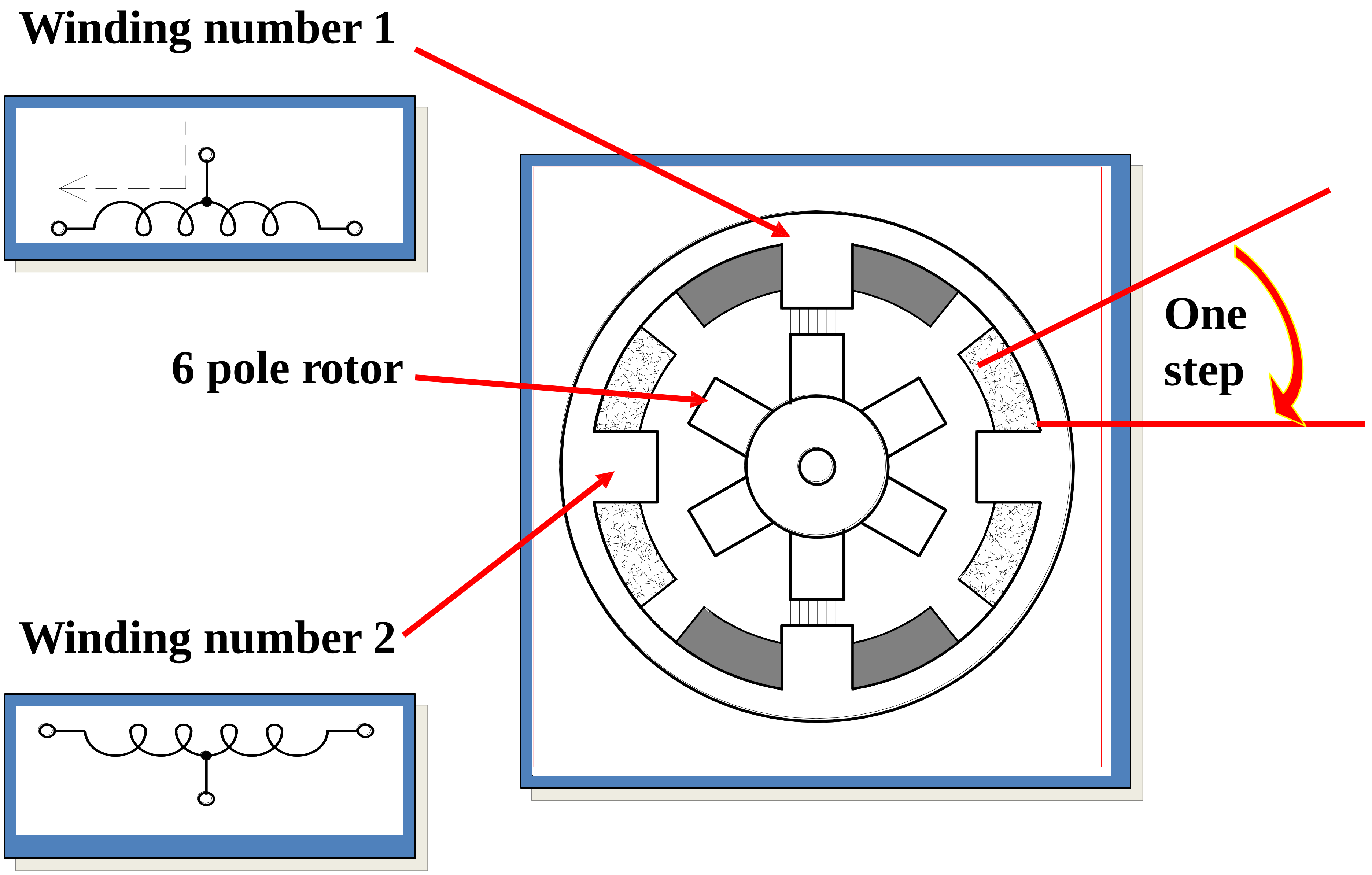


Four Steps per revolution i.e. 90 deg. steps.

Half Step Operation

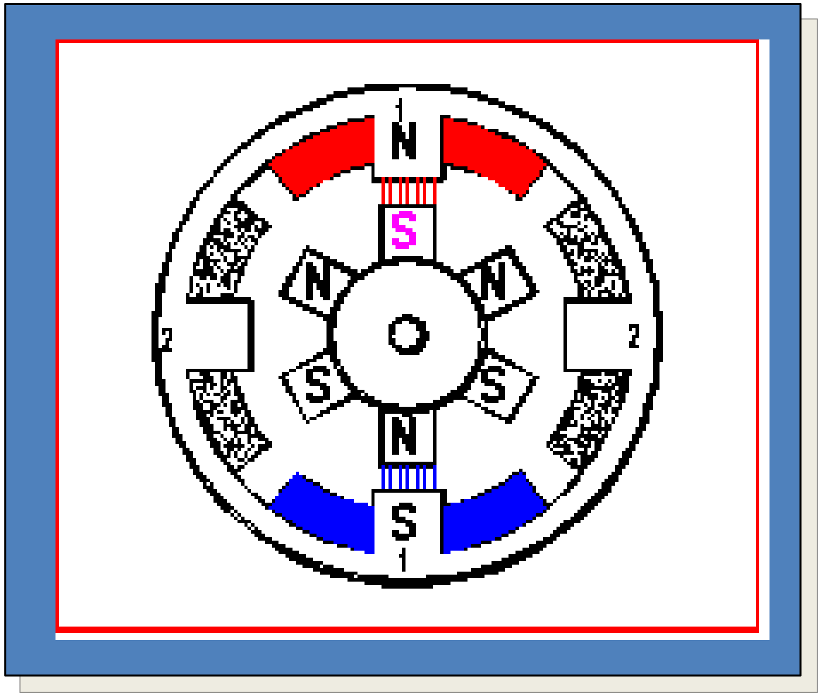


Eight steps per. revolution i.e. 45 deg. steps.



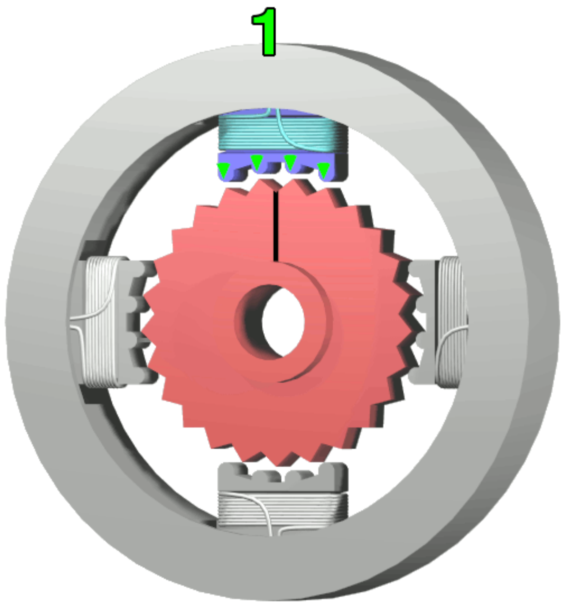
Winding number 1
6 pole rotor
Winding number 2
One step

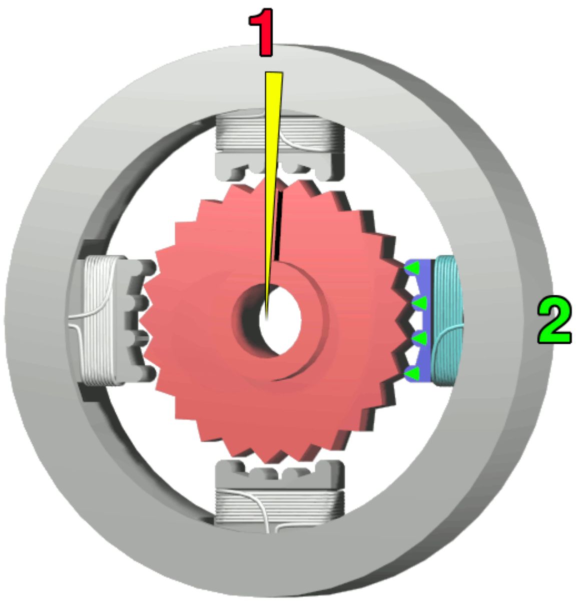
Six pole rotor, two electro magnets.



How many steps are required for one complete revolution?

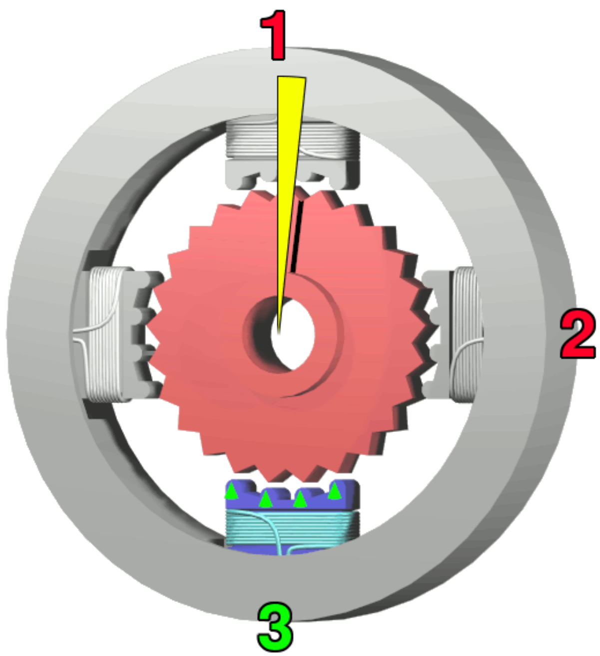
Practical Stepper motor operation



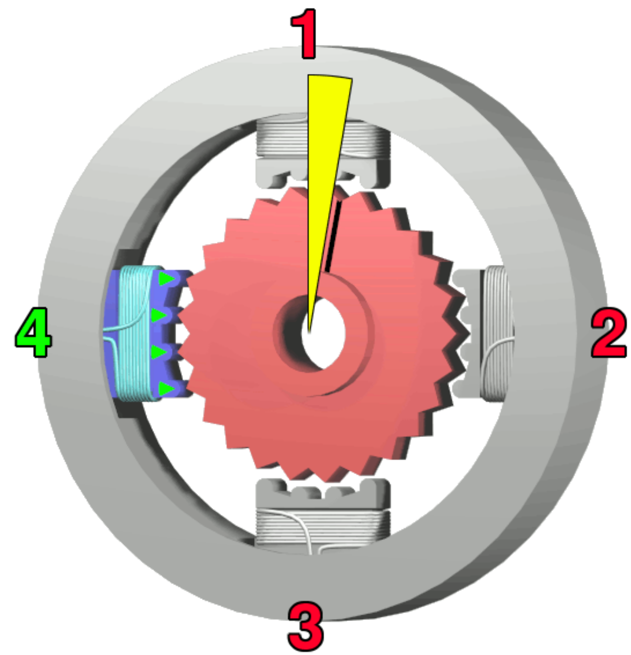


The top electromagnet (1) is turned on, attracting the nearest teeth of a gear-shaped iron rotor. With the teeth aligned to electromagnet 1, they will be slightly offset from electromagnet 2

The top electromagnet (1) is turned off, and the right electromagnet (2) is energized, pulling the nearest teeth slightly to the right. This results in a rotation of 3.6° in this example.

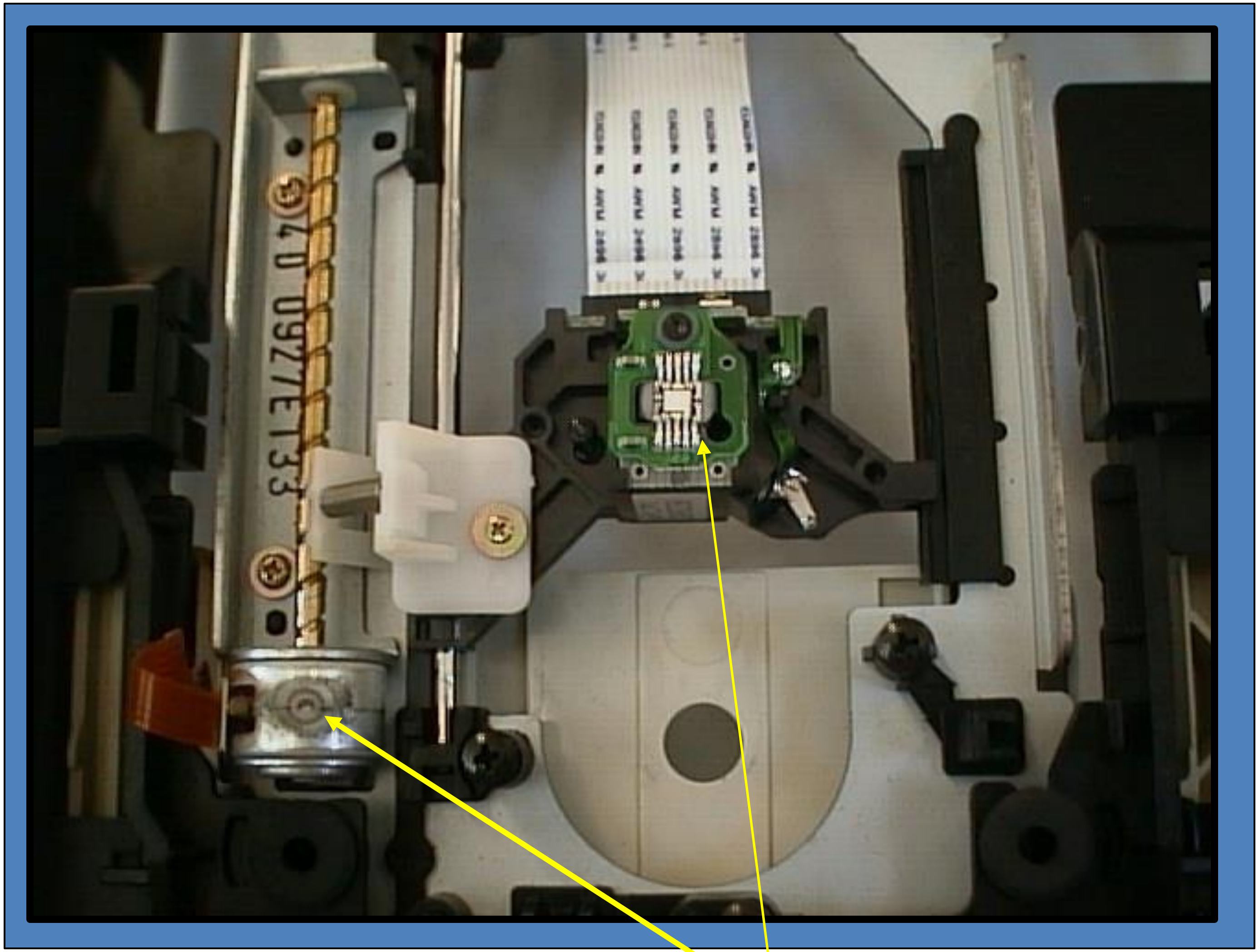


The bottom electromagnet (3) is energized; another 3.6° rotation occurs.



The left electromagnet (4) is enabled, rotating again by 3.6°. When the top electromagnet (1) is again enabled, the teeth in the sprocket will have rotated by one tooth position; since there are 25 teeth, it will take 100 steps to make a full rotation in this example.

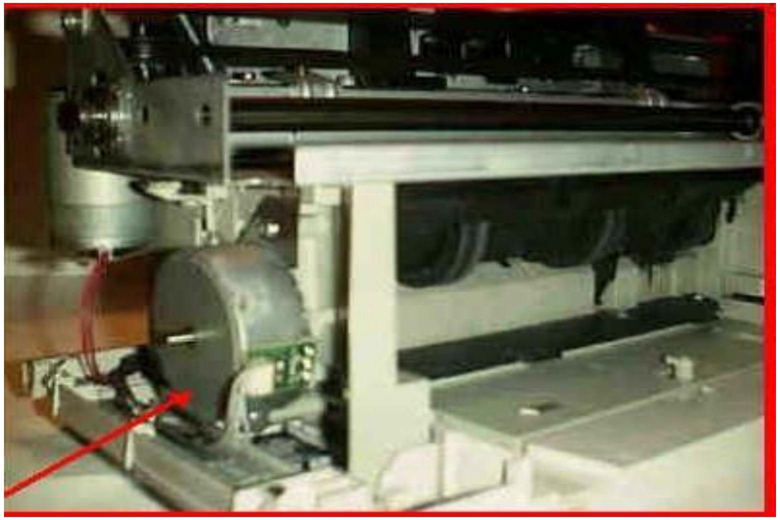
Stepper motor applications



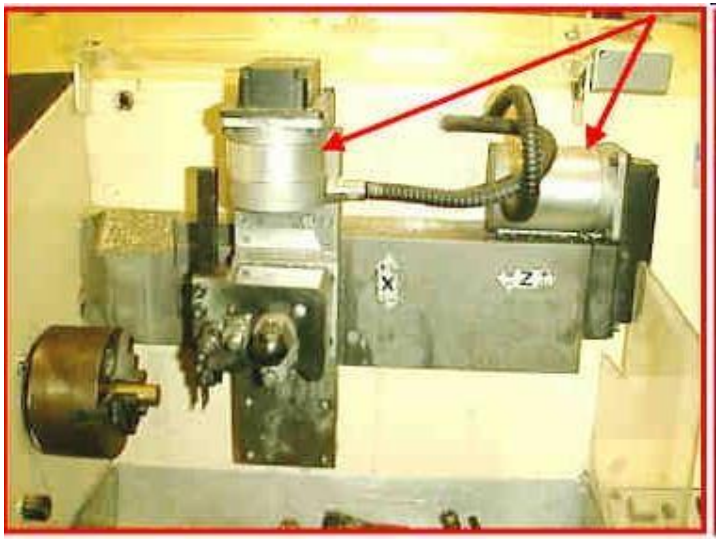
Stepping Motor to move read-write head

Stepper motor applications

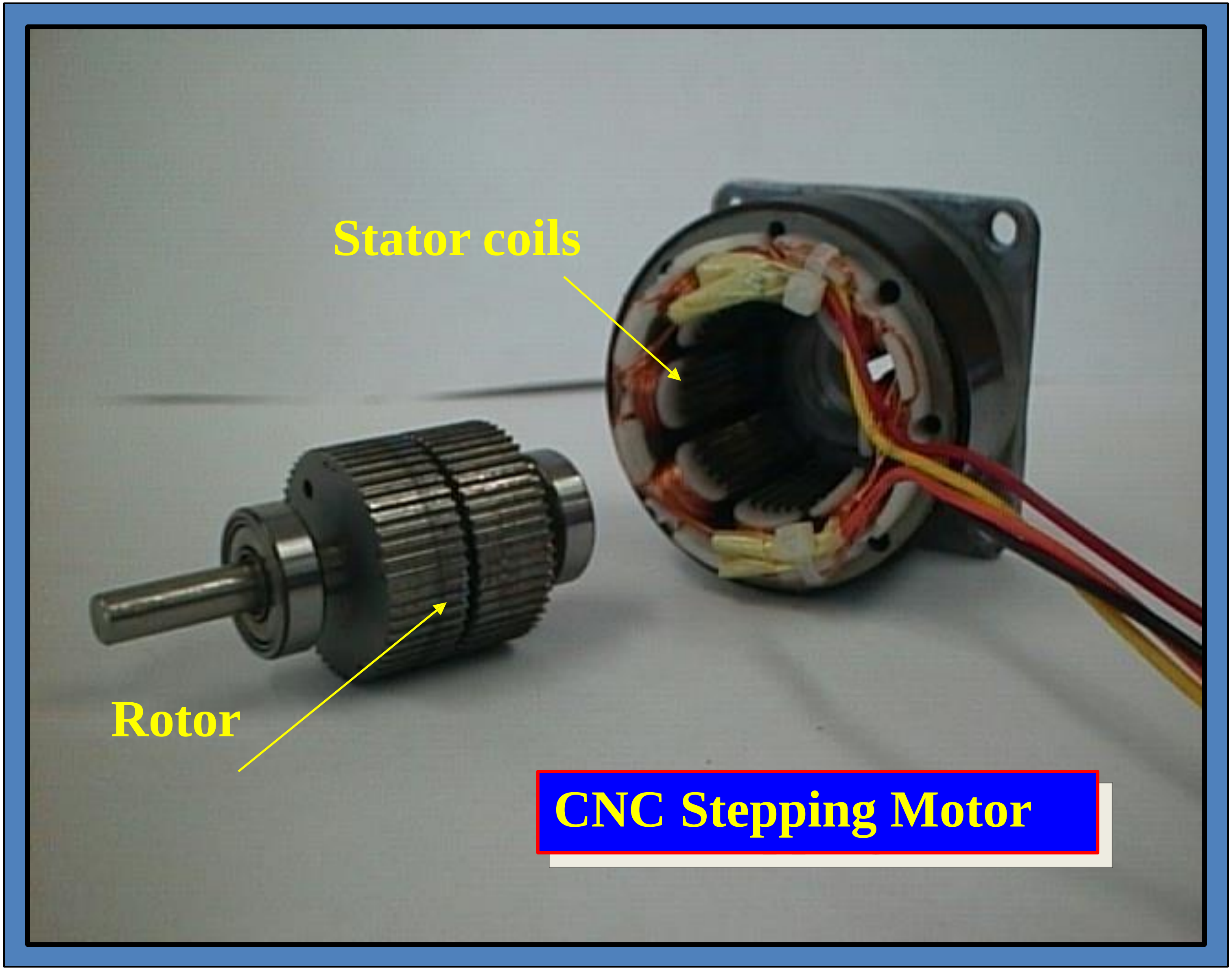
Paper feeder on printers



Stepper motors



CNC lathes


Stator coils
Rotor
CNC Stepping Motor

Advantages / Disadvantages

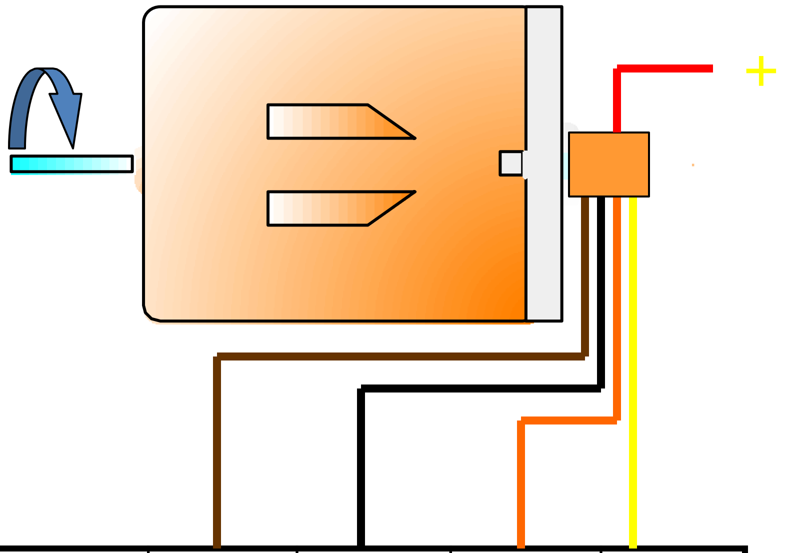
Advantages:-

- Low cost for control achieved
- Ruggedness
- Simplicity of construction
- Can operate in an open loop control system
- Low maintenance
- Less likely to stall or slip
- Will work in any environment

Disadvantages:-

- Require a dedicated control circuit
- Use more current than D.C. motors
- High torque output achieved at low speeds

Control sequence to turn a stepper motor

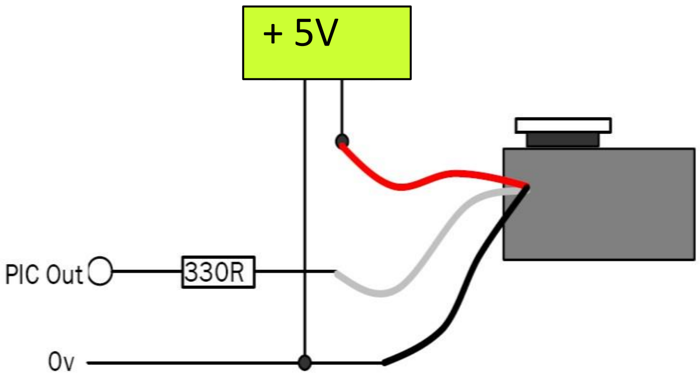


CW

Step 1	0	0	1	1
Step 2	1	0	1	0
Step 3	1	1	0	0
Step 4	0	1	0	1

CCW

Servo Motor Detail



Actuator

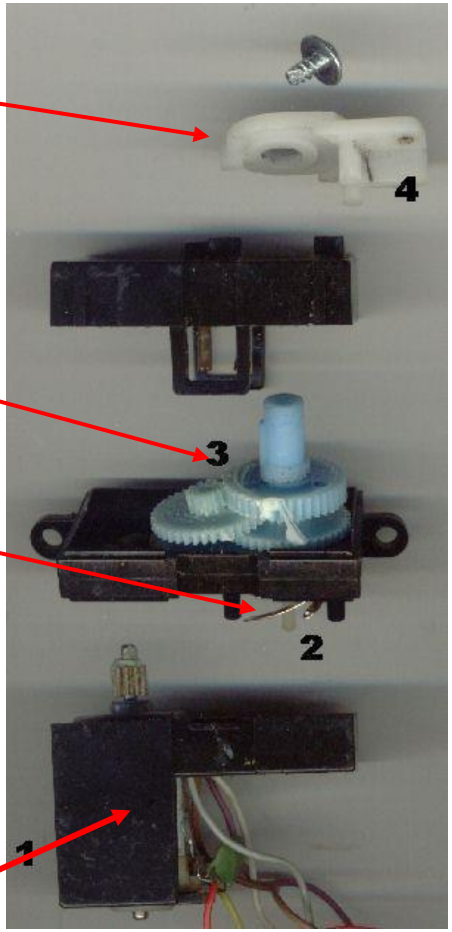
Reduction gear

Position feedback

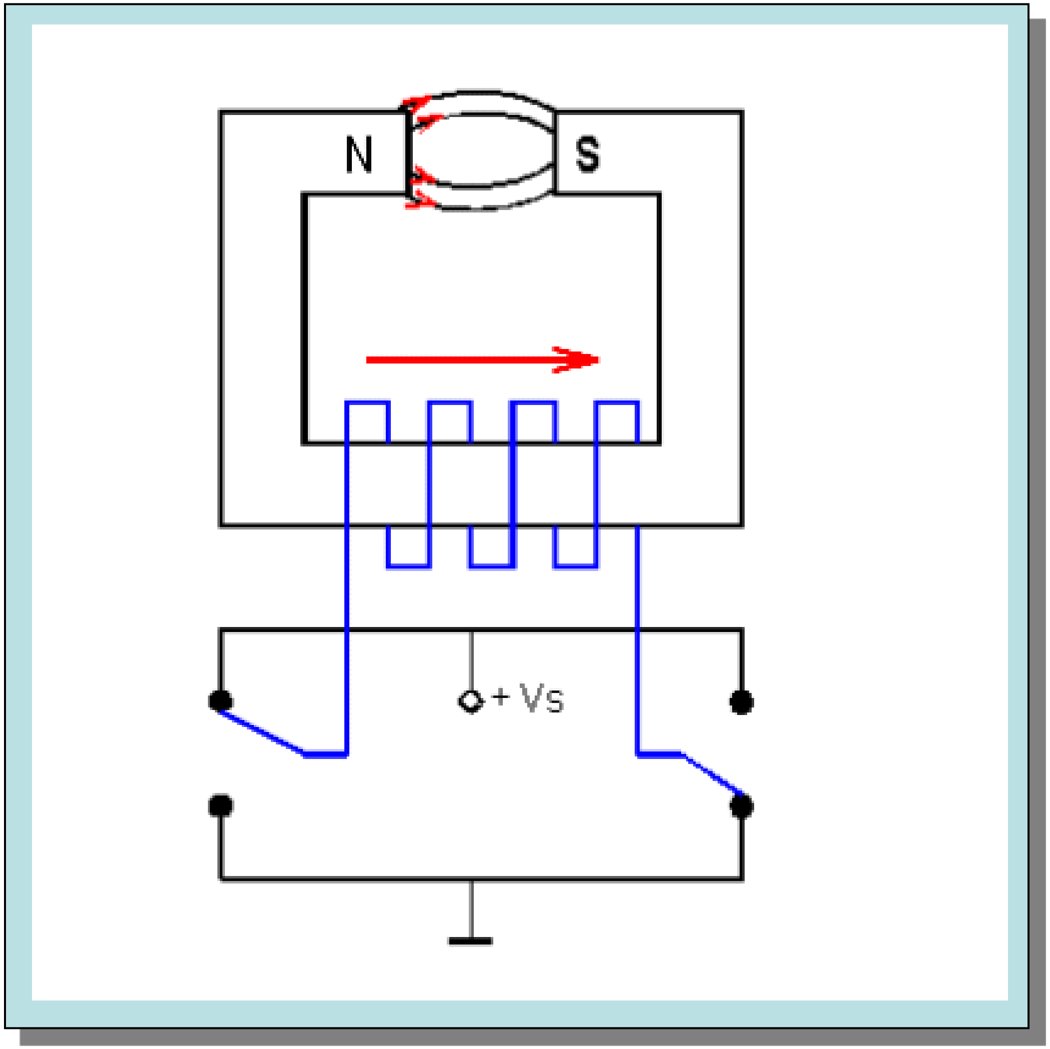
Potentiometer

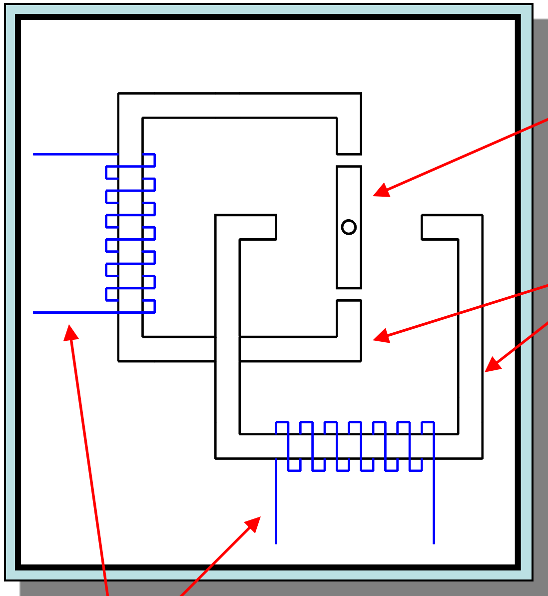
(closed loop system)

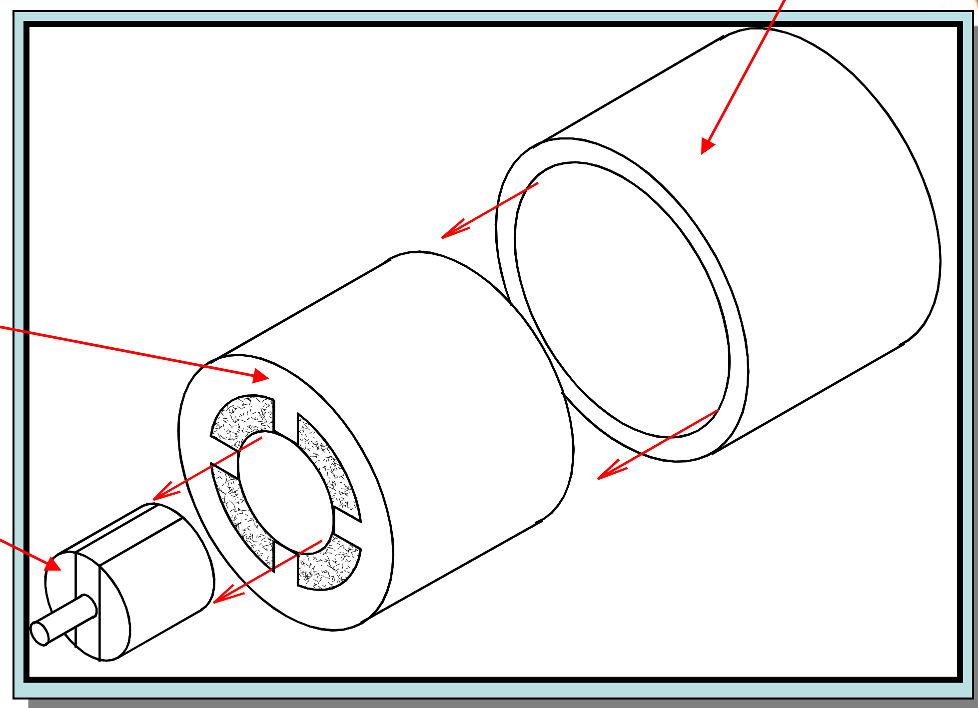
Small electric DC motor

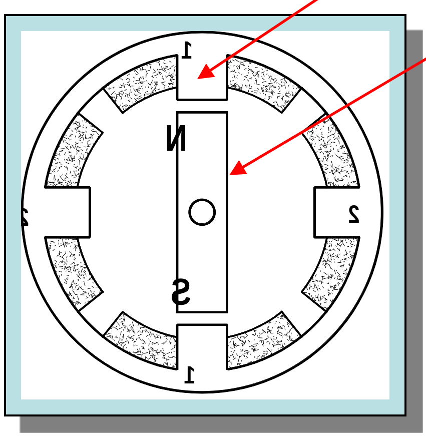


Stepper Motor / Electro magnet









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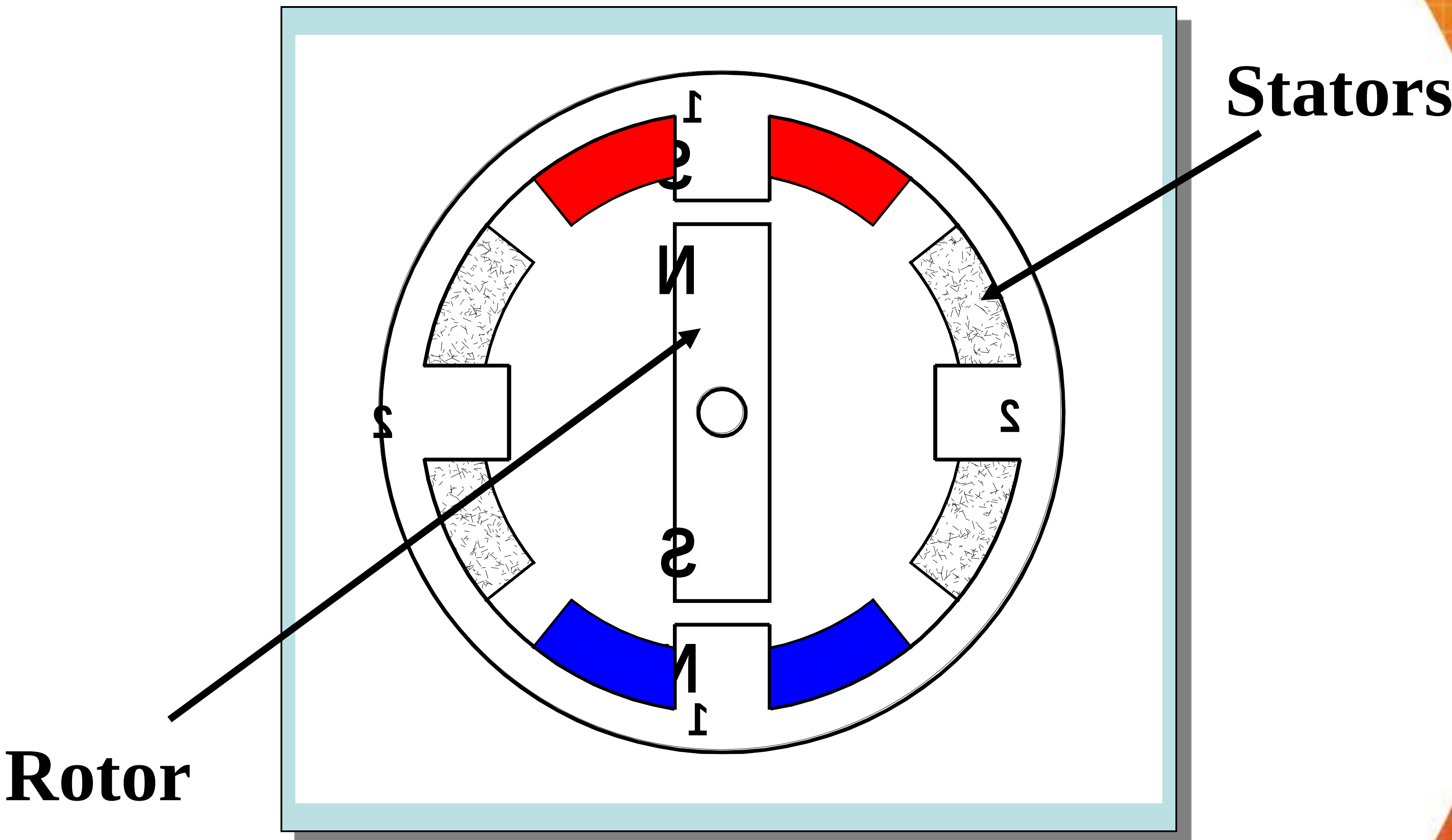
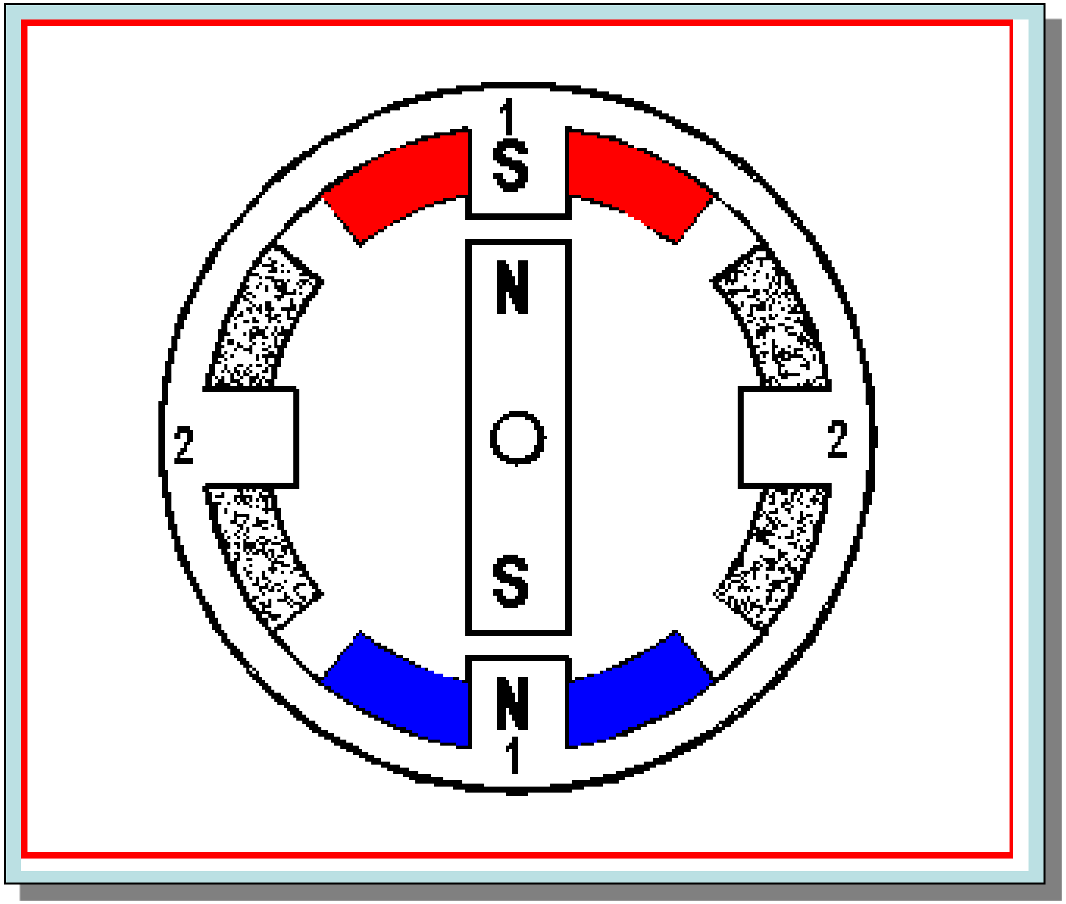
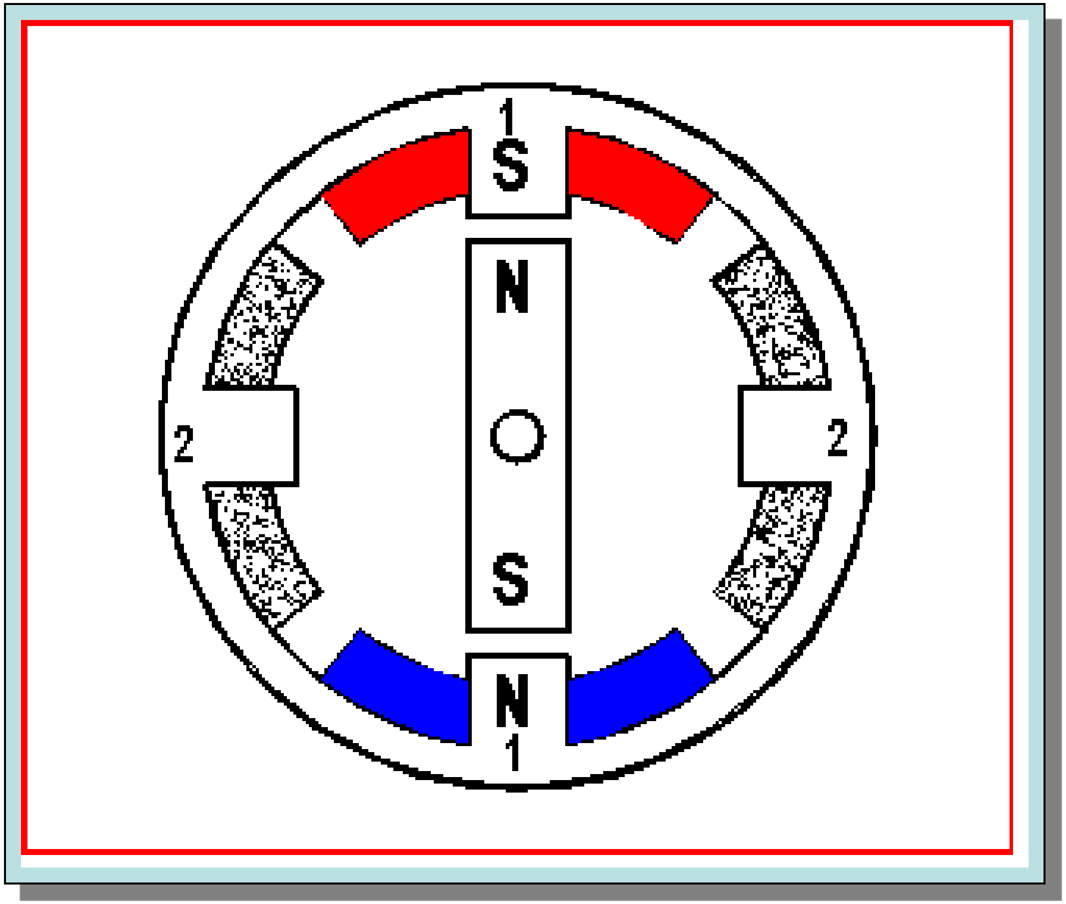


Full Step Operation



Four Steps per revolution i.e. 90 deg. steps.

Half Step Operation



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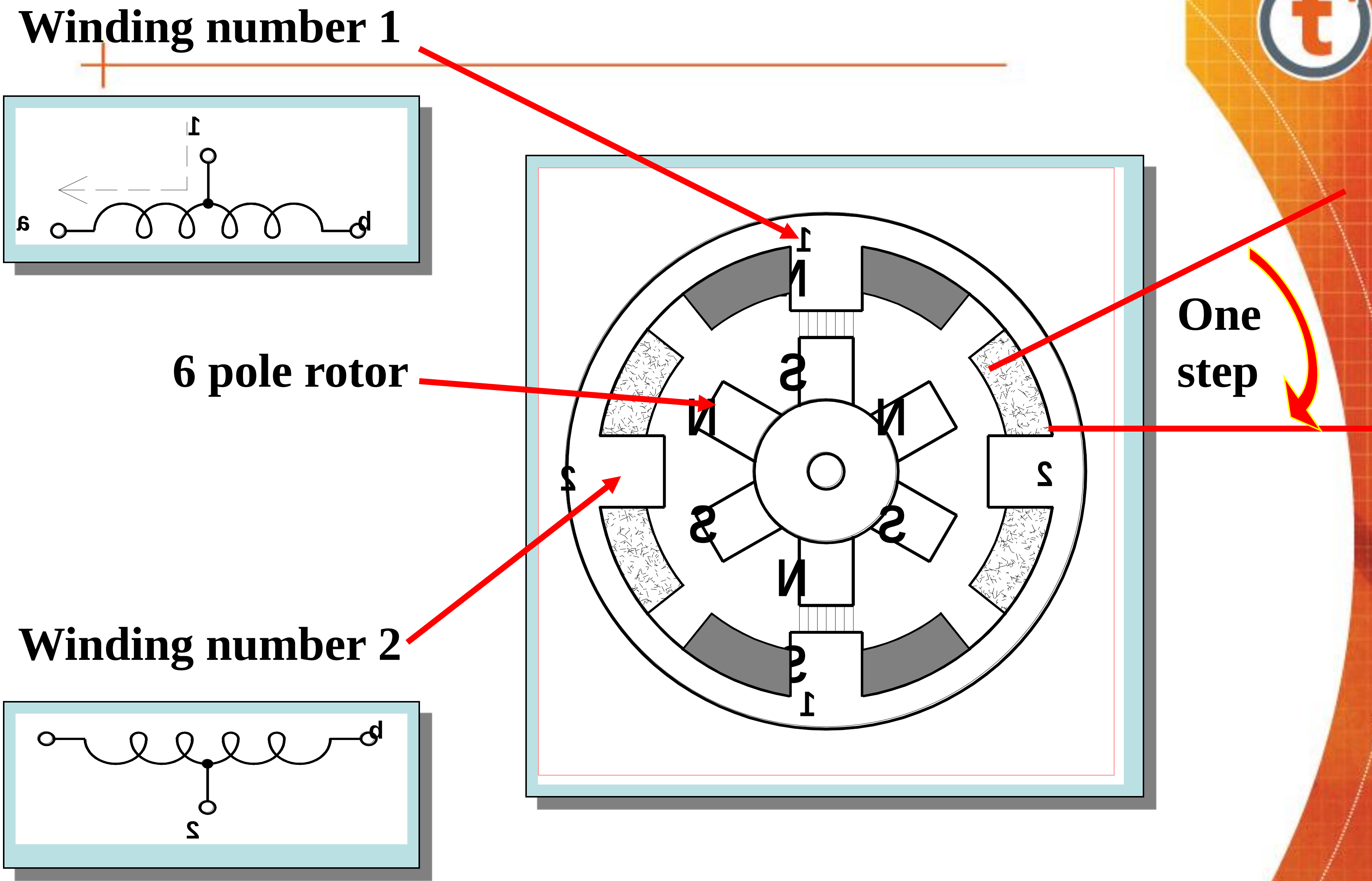
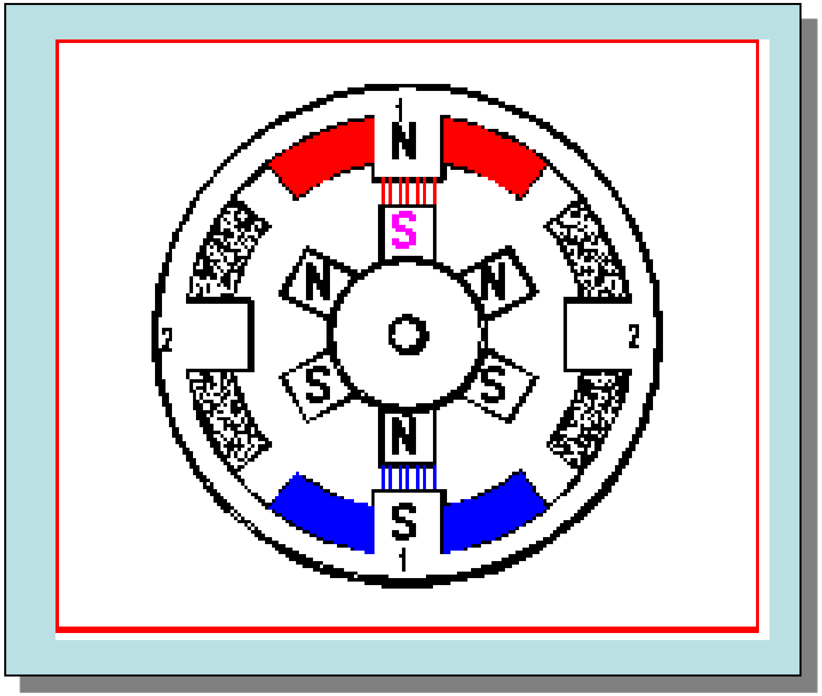

Winding number 1
6 pole rotor
One step
Winding number 2

Six pole rotor, two electro magnets.



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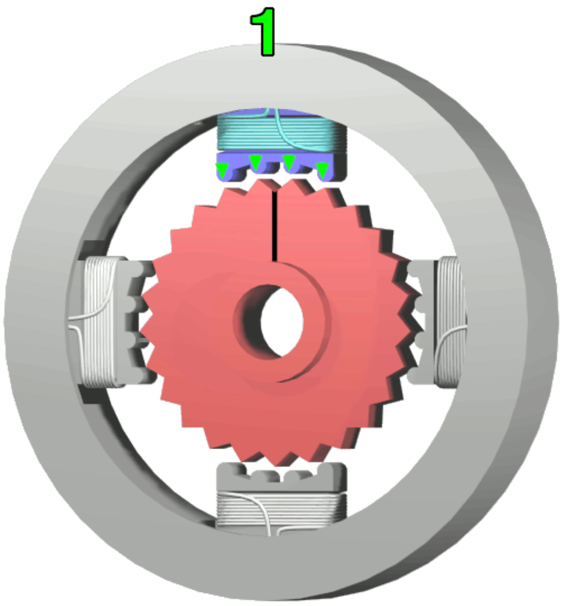
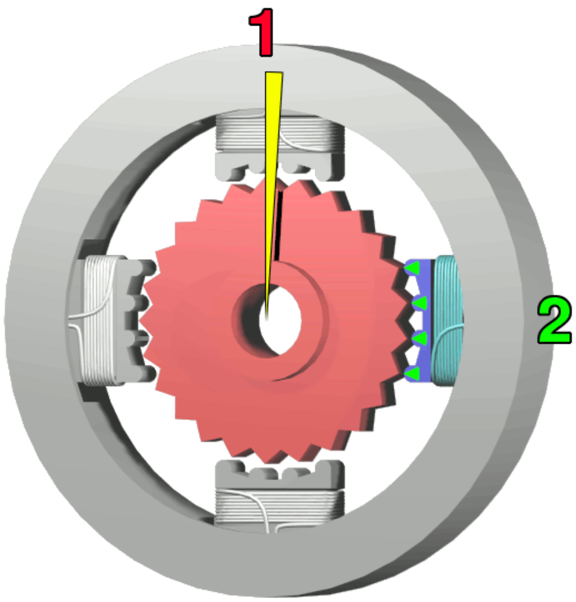
Practical Stepper motor operation





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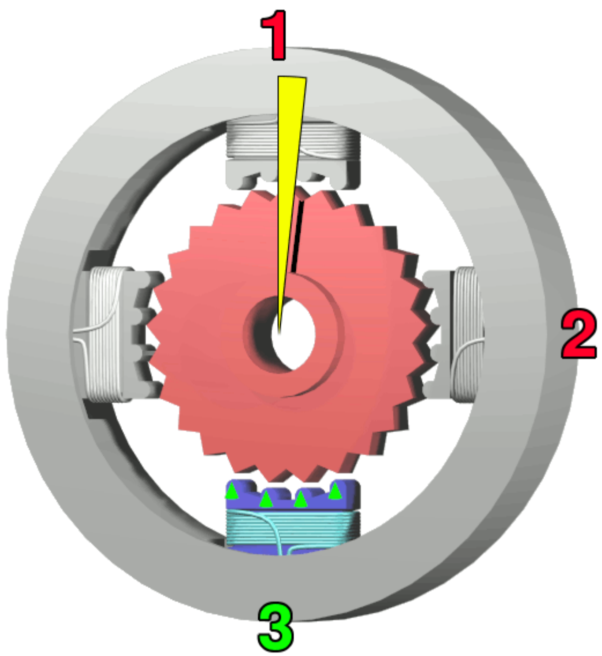

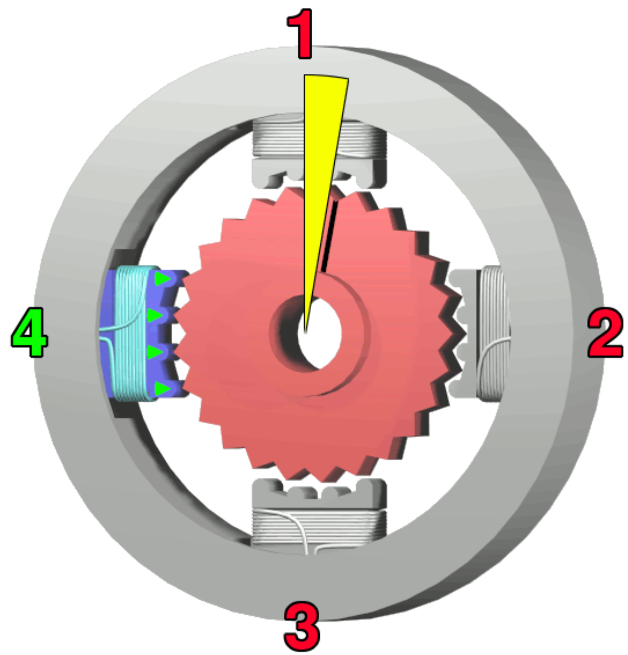

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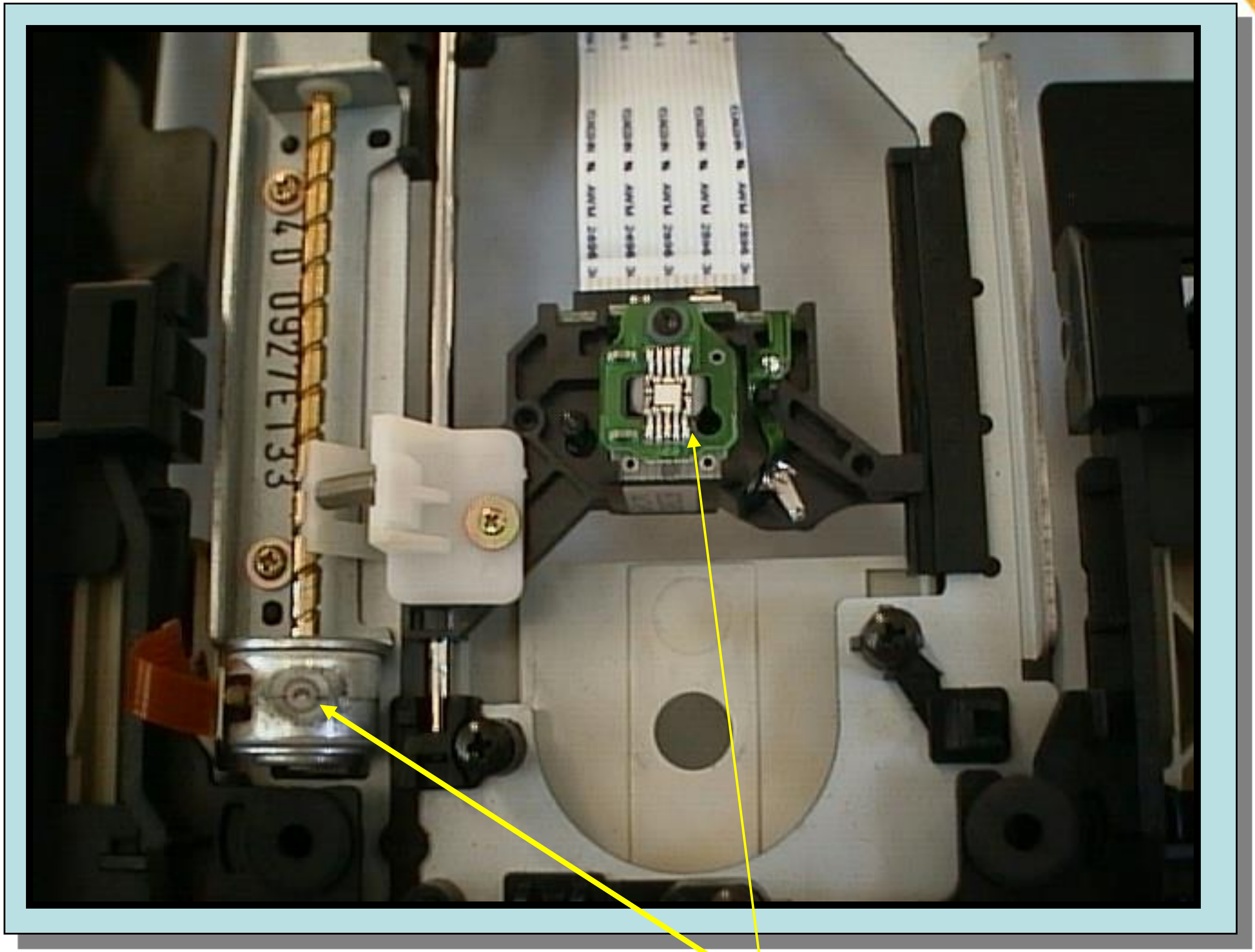
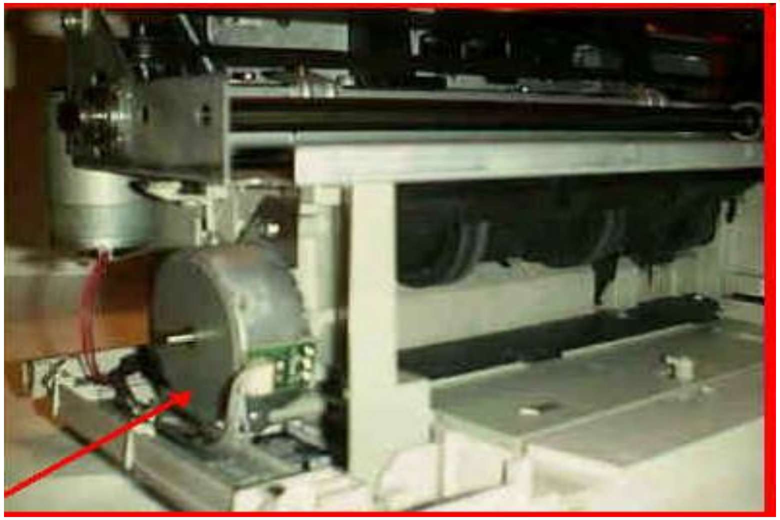
Stepper motor applications



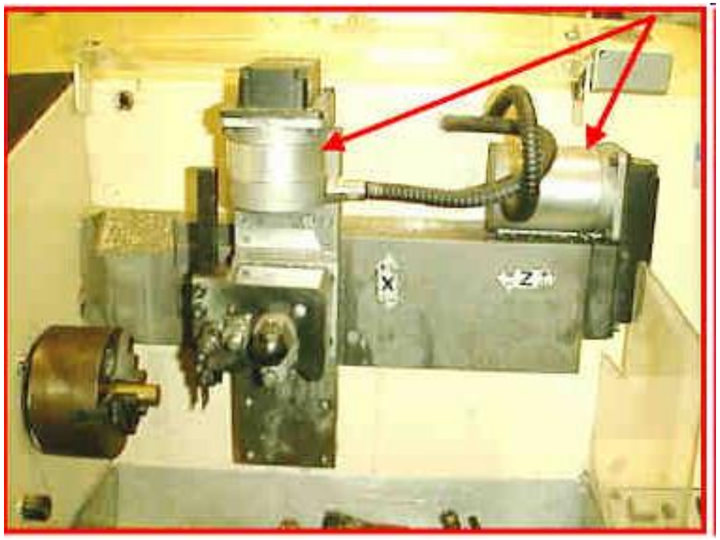
Stepping Motor to move read-write head

Stepper motor applications

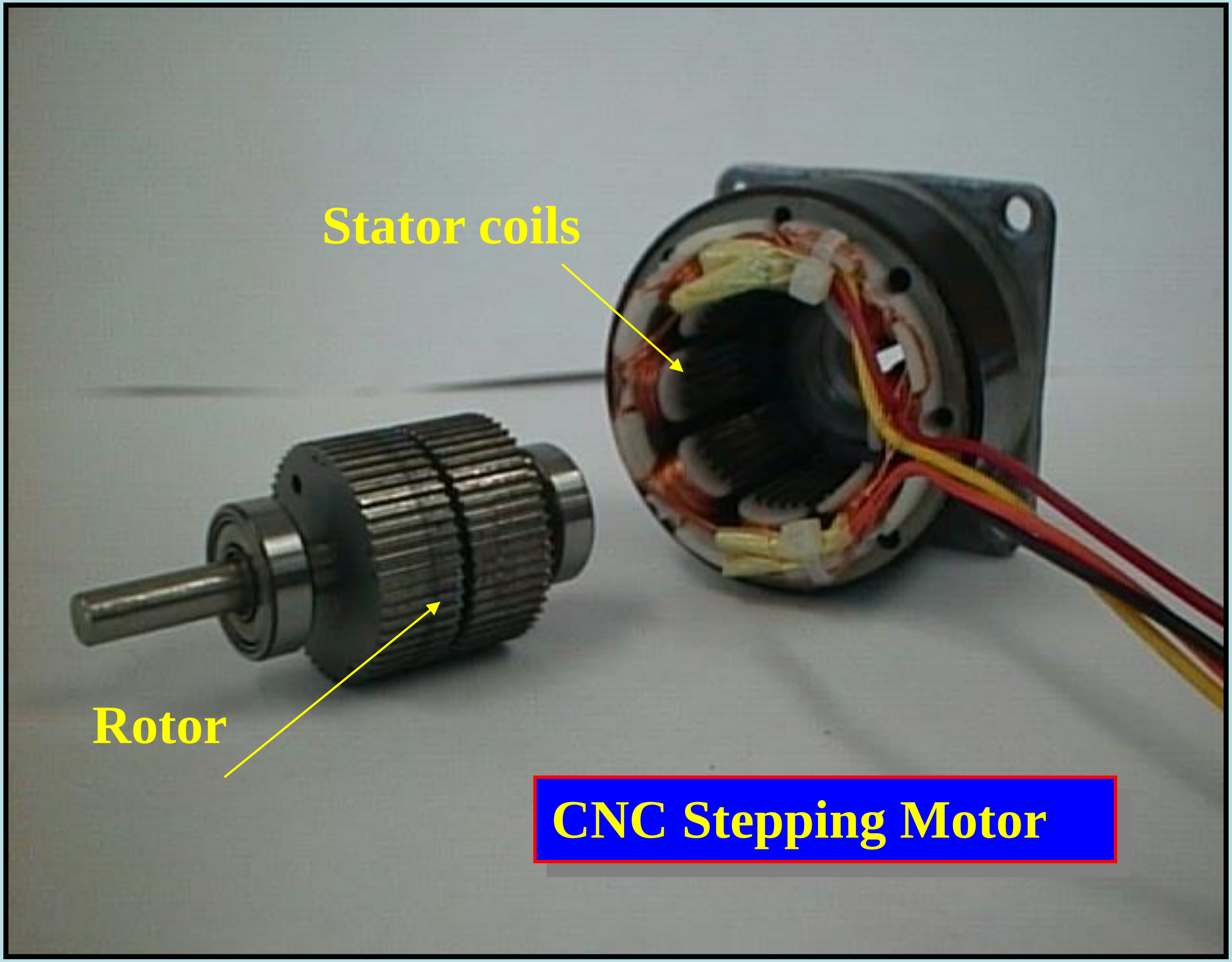
Paper feeder on printers



Stepper motors



CNC lathes


Stator coils
Rotor
CNC Stepping Motor

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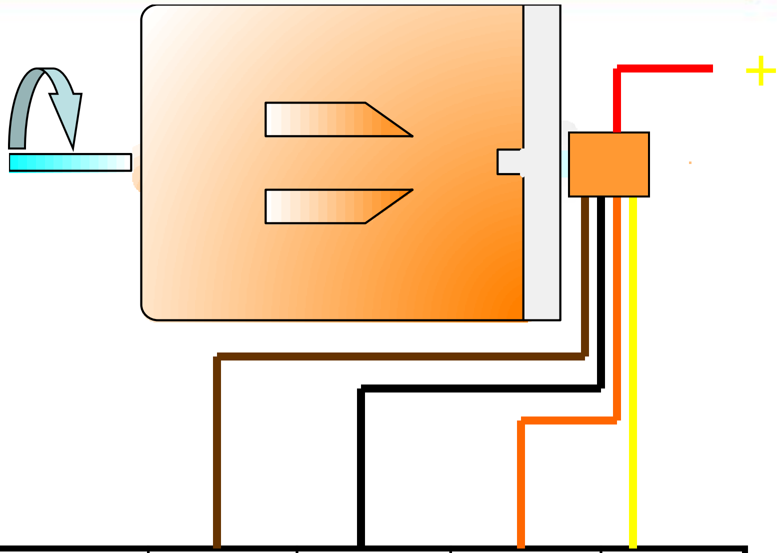
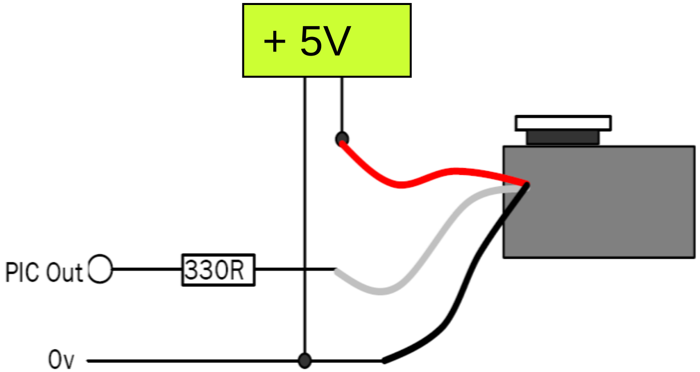
Control sequence to turn a stepper motor



CW ↓ / CCW ↑

Step 1	0	0	1	1
Step 2	1	0	1	0
Step 3	1	1	0	0
Step 4	0	1	0	1

Servo Motor Detail



Actuator

Reduction gear

Position feedback

Potentiometer

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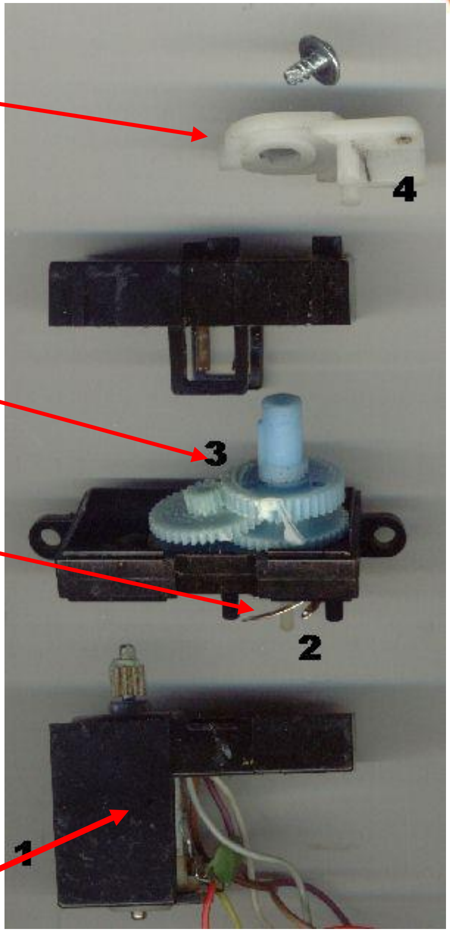
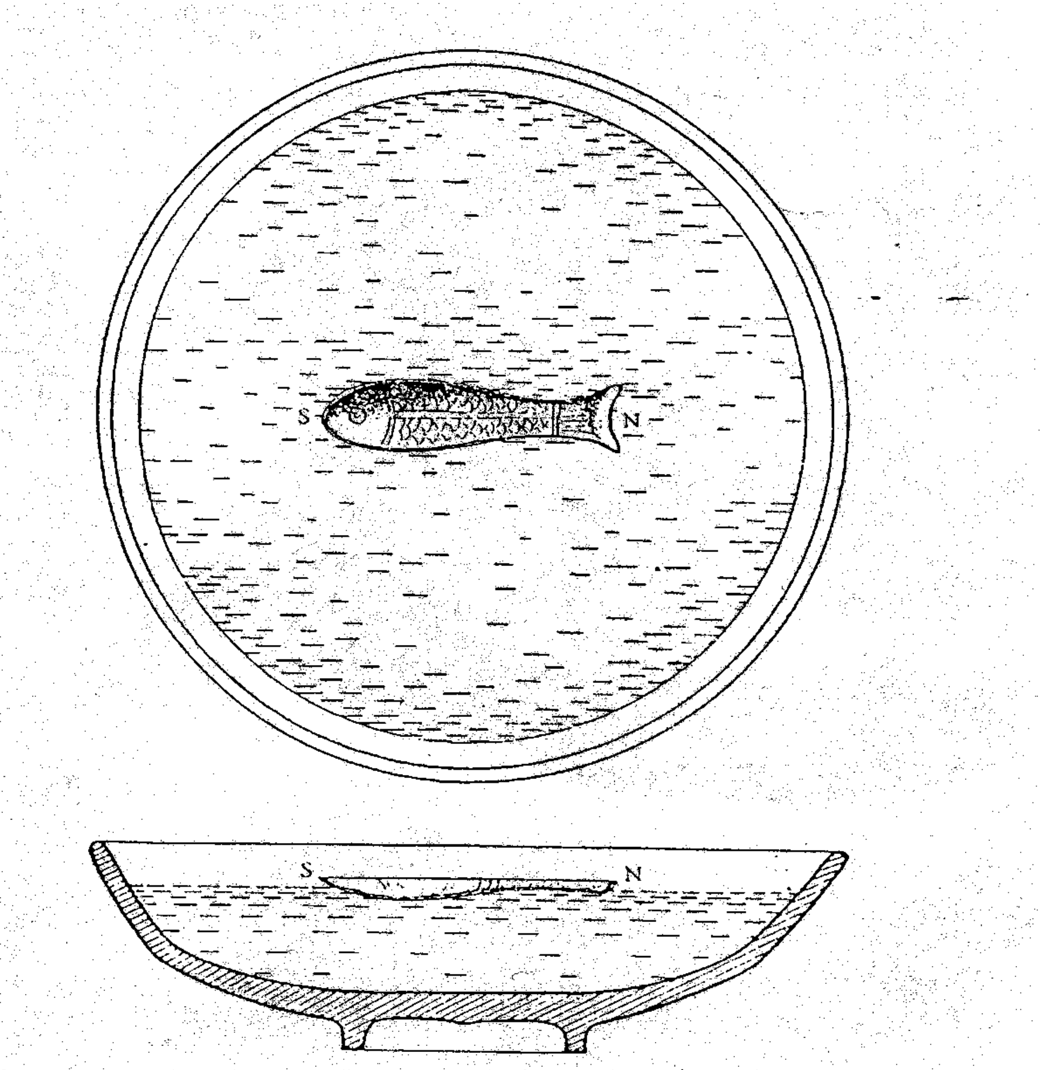
Small electric DC motor





Magnetism

- One of the first compasses, a fish shaped iron leaf was mentioned in the Wu Ching Tsung Yao written in 1040

Trinity College, Dublin

Electromagnetic Revolution

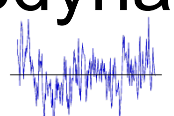
$$\nabla \cdot \vec{D} = \rho$$

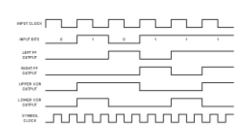
$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \cdot \vec{B} = 0$$

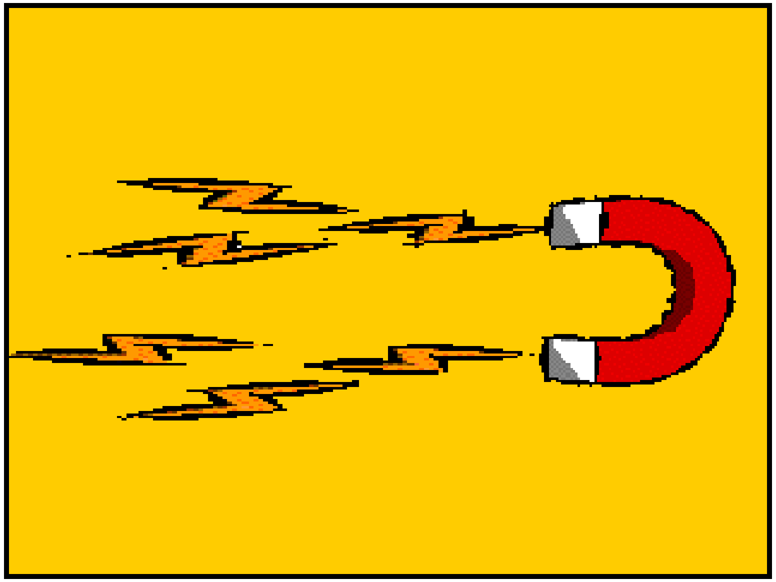
$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

- These four equations epitomize the electromagnetic revolution. Richard Feynman claimed that "ten thousand years from now, there can be little doubt that the most significant event of the 19th century will be judged as Maxwell's discovery of the laws of electrodynamics"



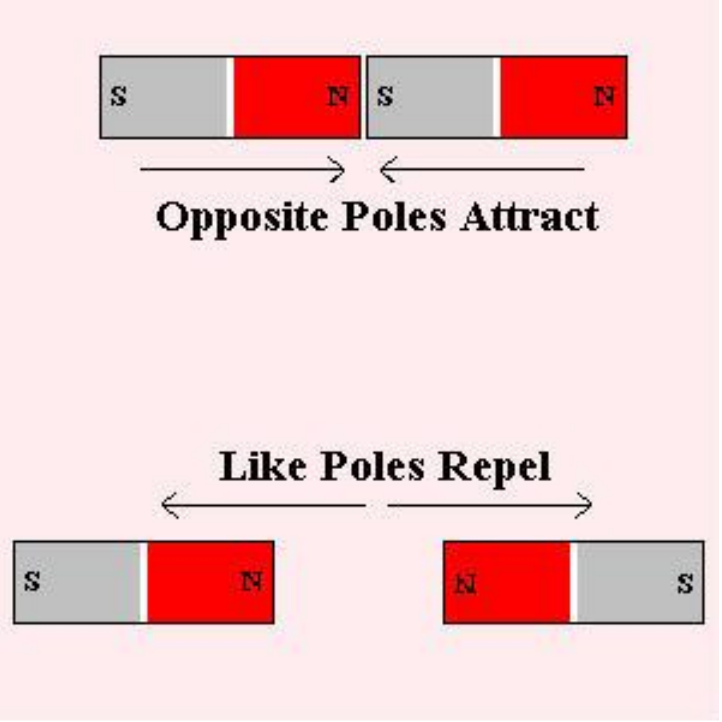


Magnetic Attraction

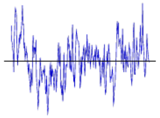


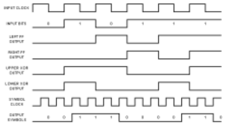
- It is possible to produce motion using magnetic attraction and/or repulsion
- Either permanent magnets or electromagnets or both can be used

Magnetic Attraction and Repulsion

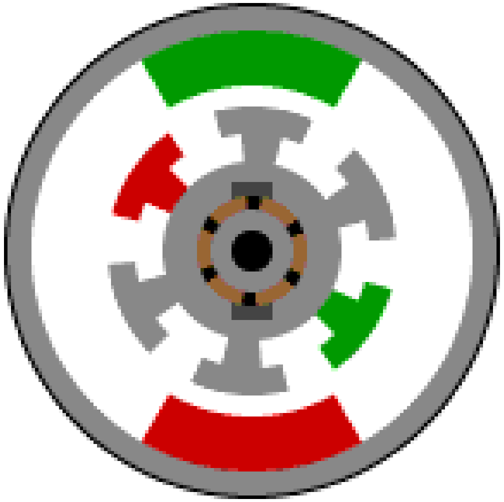


- One of the many facts we all recall from our earliest science education



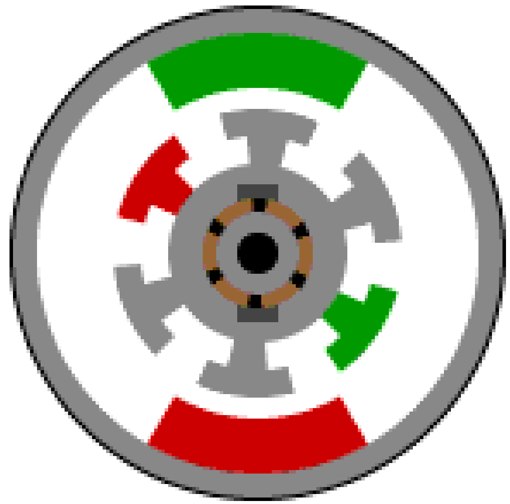


DC Motors



- The stator is the stationary outside part of a motor. The rotor is the inner part which rotates. In the motor animations, red represents a magnet or winding with a north polarization, while green represents a magnet or winding with a south polariztion. Opposite, red and green, polarities attract.

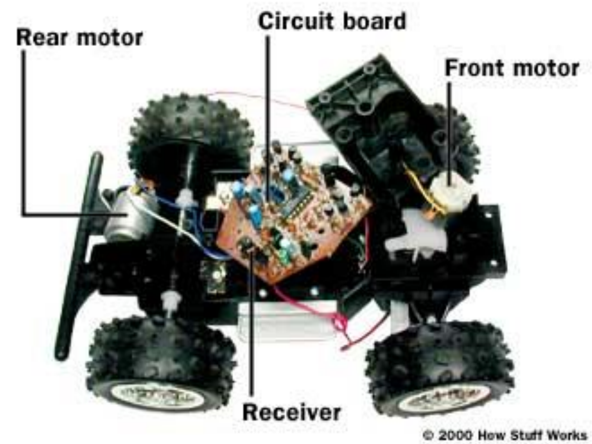
DC Motors



- Just as the rotor reaches alignment, the brushes move across the commutator contacts and energize the next winding. In the animation the commutator contacts are brown and the brushes are dark grey. A yellow spark shows when the brushes switch to the next winding.

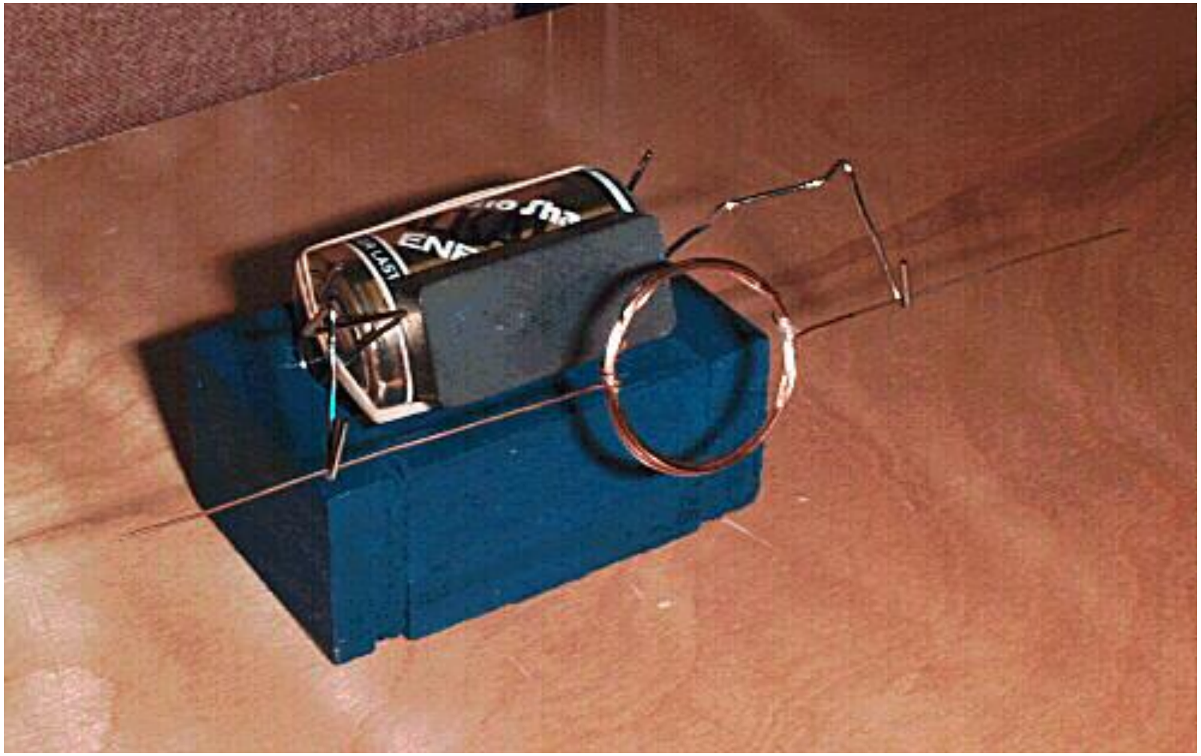
DC Motor Applications

- Automobiles
  - Windshield Wipers
  - Door locks
  - Window lifts
  - Antenna retractor
  - Seat adjust
  - Mirror adjust
  - Anti-lock Braking System



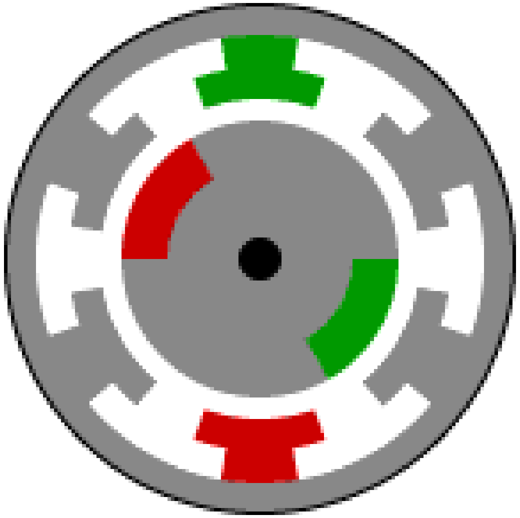
- Cordless hand drill
- Electric lawnmower
- Fans
- Toys
- Electric toothbrush
- Servo Motor

Beakman’s Motor



- A simple DC motor made with a battery, two paperclips, a rubber band and about 1 meter of enameled wire.

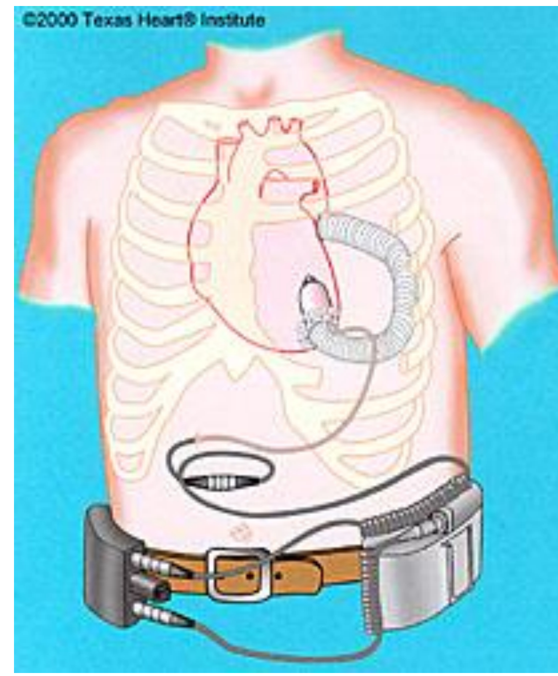
Brushless DC Motors



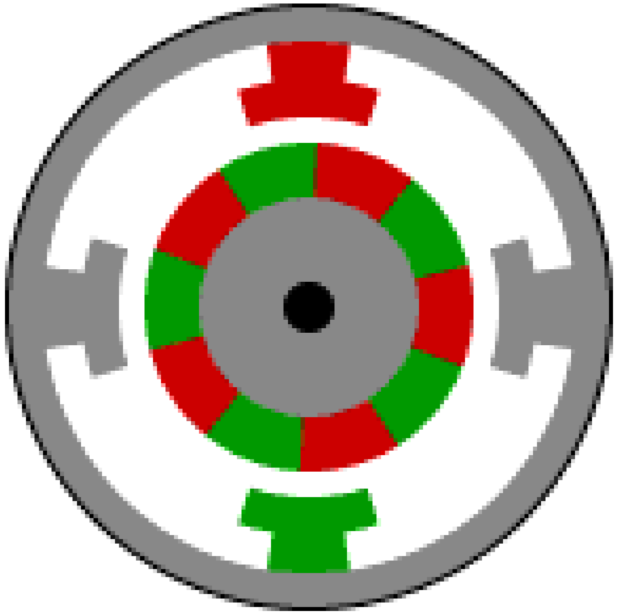
- A brushless dc motor has a rotor with permanent magnets and a stator with windings. It is essentially a dc motor turned inside out. The control electronics replace the function of the commutator and energize the proper winding.

Brushless DC Motor Applictions

- Medical: centrifuges, orthoscopic surgical tools, respirators, dental surgical tools, and organ transport pump systems
- Model airplanes, cars, boats, helicopters
- Microscopes
- Tape drives and winders
- Artificial heart

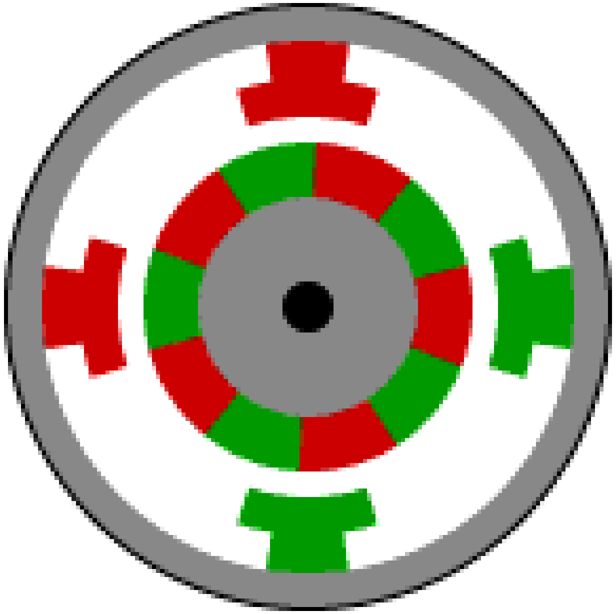


Full Stepper Motor



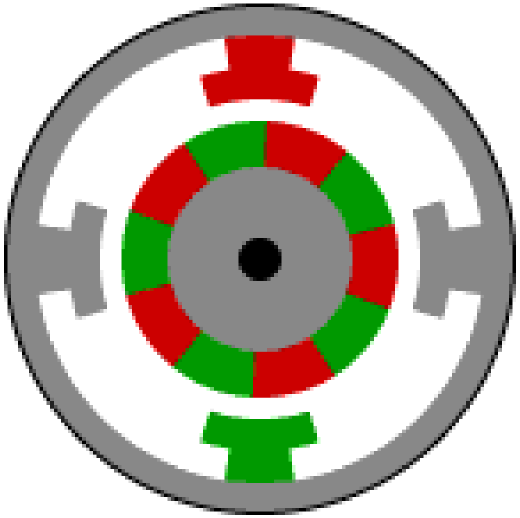
- This animation demonstrates the principle for a stepper motor using full step commutation. The rotor of a permanent magnet stepper motor consists of permanent magnets and the stator has two pairs of windings. Just as the rotor aligns with one of the stator poles, the second phase is energized. The two phases alternate on and off and also reverse polarity. There are four steps. One phase lags the other phase by one step. This is equivalent to one forth of an electrical cycle or 90°.

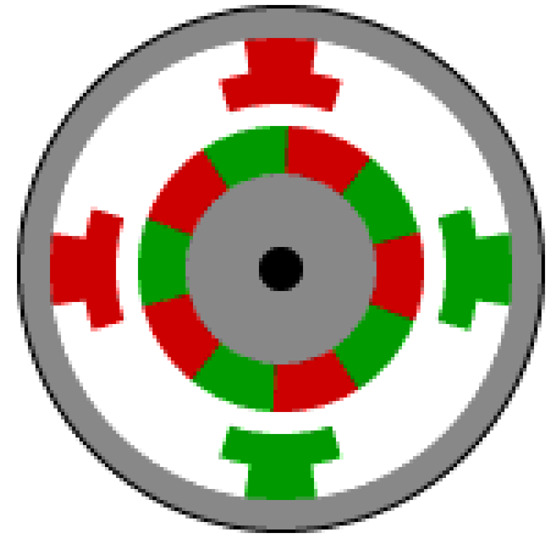
Half Stepper Motor



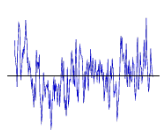
- This animation shows the stepping pattern for a half-step stepper motor. The commutation sequence for a half-step stepper motor has eight steps instead of four. The main difference is that the second phase is turned on before the first phase is turned off. Thus, sometimes both phases are energized at the same time. During the half-steps the rotor is held in between the two full-step positions. A half-step motor has twice the resolution of a full step motor. It is very popular for this reason.

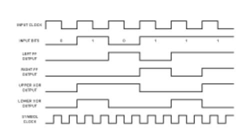
Stepper Motors



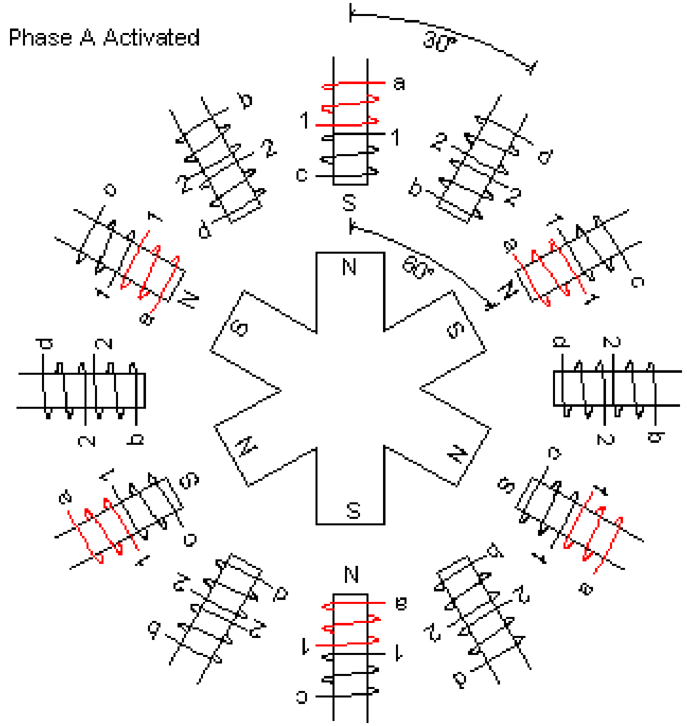


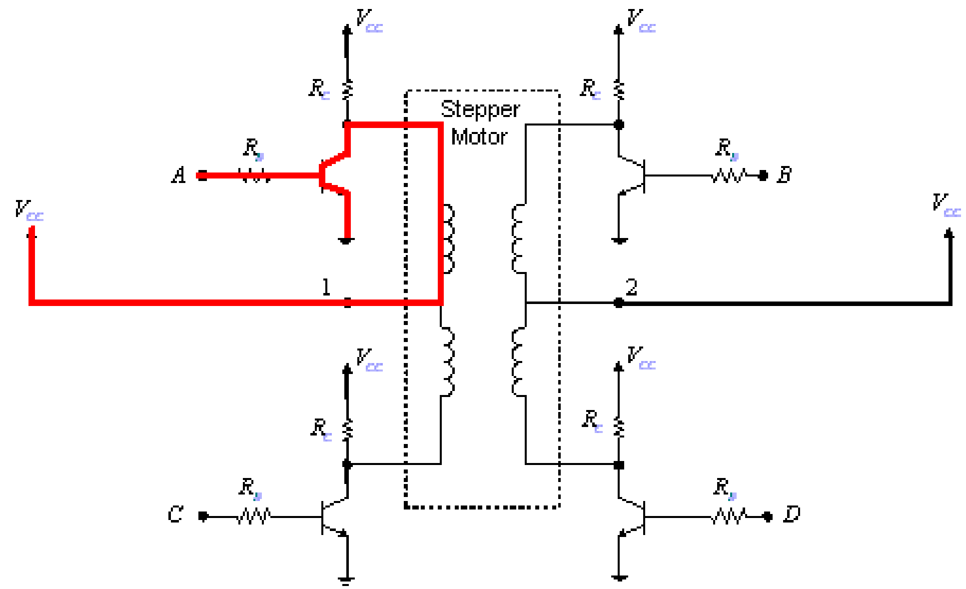
- This stepper motor is very simplified. The rotor of a real stepper motor usually has many poles. The animation has only ten poles, however a real stepper motor might have a hundred. These are formed using a single magnet mounted inline with the rotor axis and two pole pieces with many teeth. The teeth are staggered to produce many poles. The stator poles of a real stepper motor also has many teeth. The teeth are arranged so that the two phases are still 90° out of phase. This stepper motor uses permanent magnets. Some stepper motors do not have magnets and instead use the basic principles of a switched reluctance motor. The stator is similar but the rotor is composed of a iron laminates.





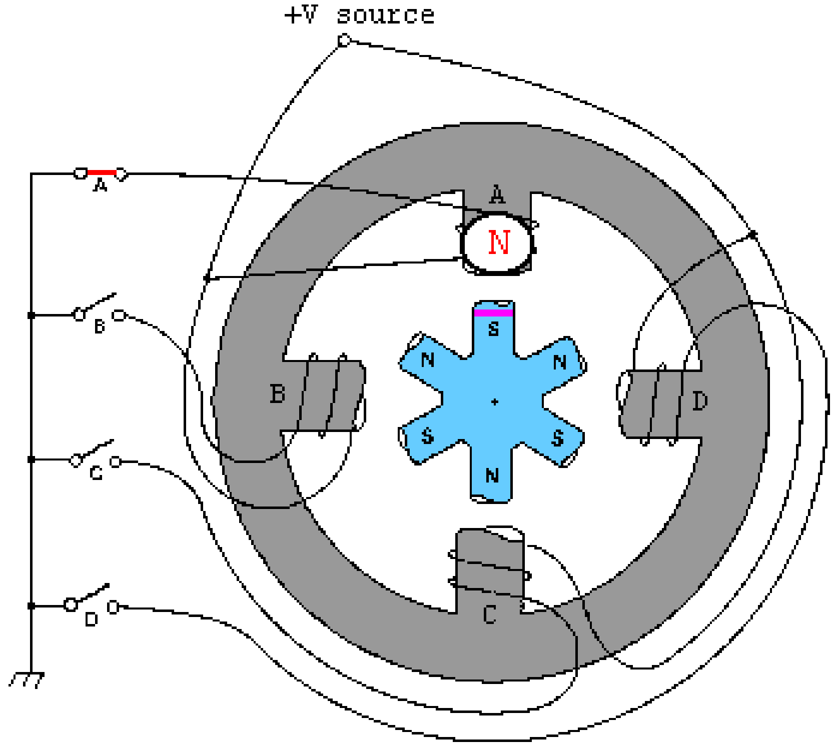
More on Stepper Motors





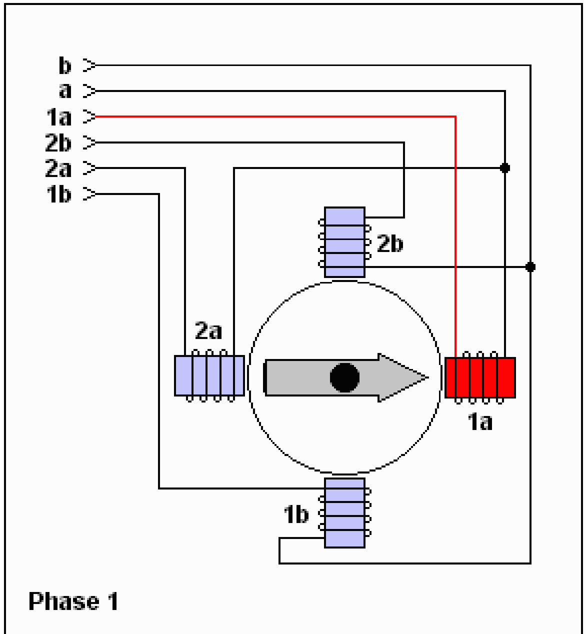
- Note how the phases are driven so that the rotor takes half steps

More on Stepper Motors



- Animation shows how coils are energized for full steps

More on Stepper Motors



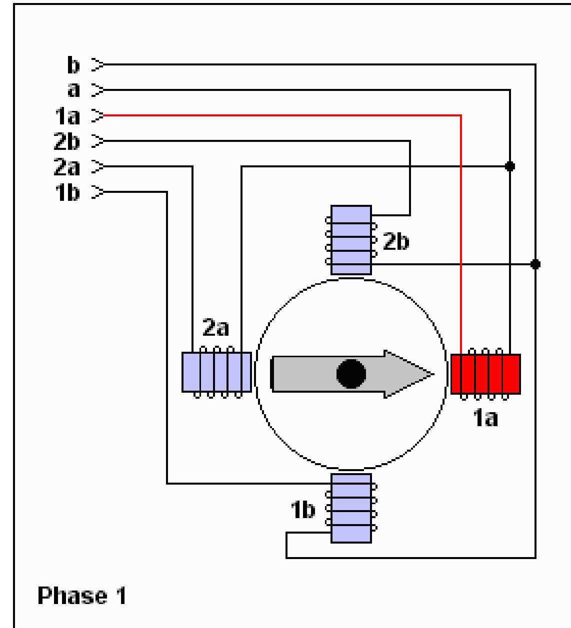
Stepper Motor Operation (Unipolar, Full step)

Clockwise Rotation

Index	1a	1b	2a	2b
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1
5	1	0	0	0
6	0	1	0	0
7	0	0	1	0
8	0	0	0	1

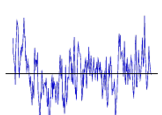
Clockwise Rotation

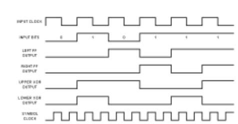
Index	1a	1b	2a	2b
1	1	0	0	0
2	1	1	0	0
3	0	1	0	0
4	0	1	1	0
5	0	0	1	0
6	0	0	1	1
7	0	0	0	1
8	1	0	0	1
9	1	0	0	0
10	1	1	0	0
11	0	1	0	0
12	0	1	1	0
13	0	0	1	0
14	0	0	1	1
15	0	0	0	1
16	1	0	0	1



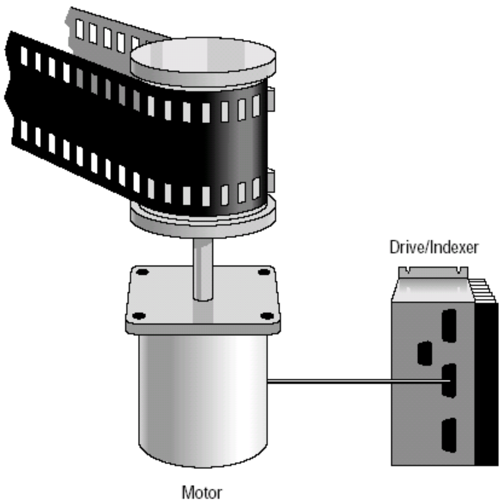
Stepper Motor Operation (Unipolar, Half step)

- Full step sequence showing how binary numbers can control the motor
- Half step sequence of binary control numbers





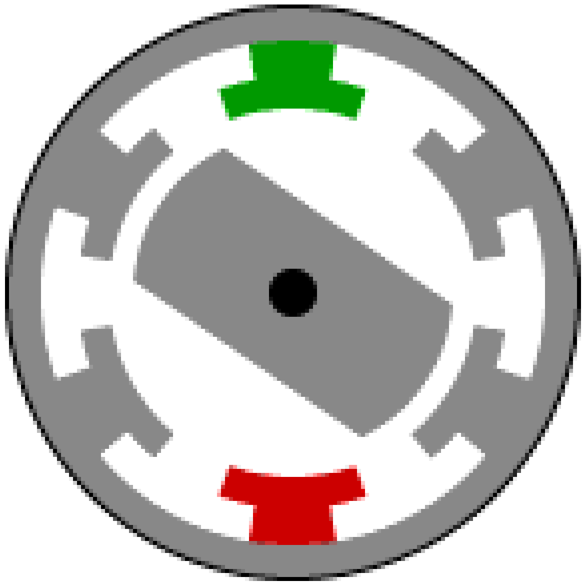
Stepper Motor Applications



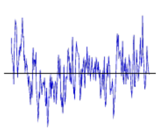
- Film Drive
- Optical Scanner
- Printers
- ATM Machines

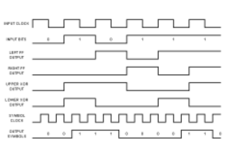
- I. V. Pump
- Blood Analyzer
- FAX Machines
- Thermostats

Switched Reluctance Motor

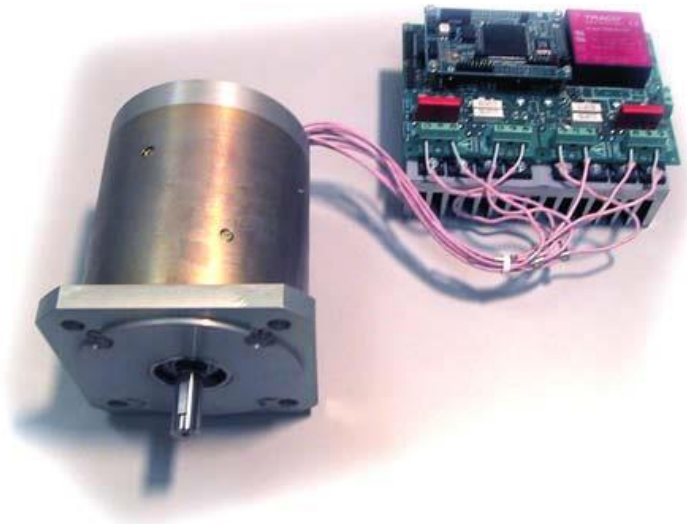


- A switched reluctance or variable reluctance motor does not contain any permanent magnets. The stator is similar to a brushless dc motor. However, the rotor consists only of iron laminates. The iron rotor is attracted to the energized stator pole. The polarity of the stator pole does not matter. Torque is produced as a result of the attraction between the electromagnet and the iron rotor in the same way a magnet is attracted to a refrigerator door. An electrically quiet motor since it has no brushes.



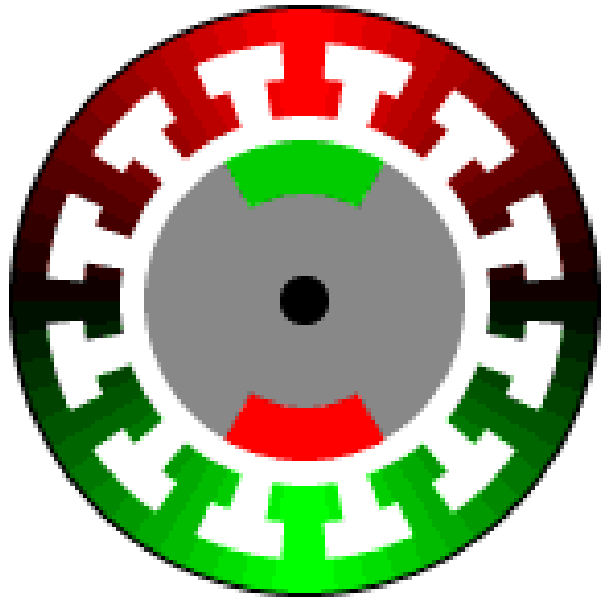


Switched Reluctance Motor Applications



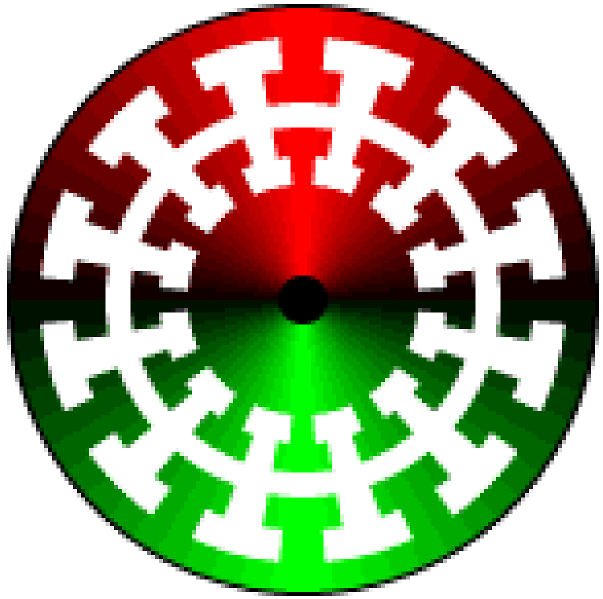
- Motor scooters and other electric and hybrid vehicles
- Industrial fans, blowers, pumps, mixers, centrifuges, machine tools
- Domestic appliances

Brushless AC Motor



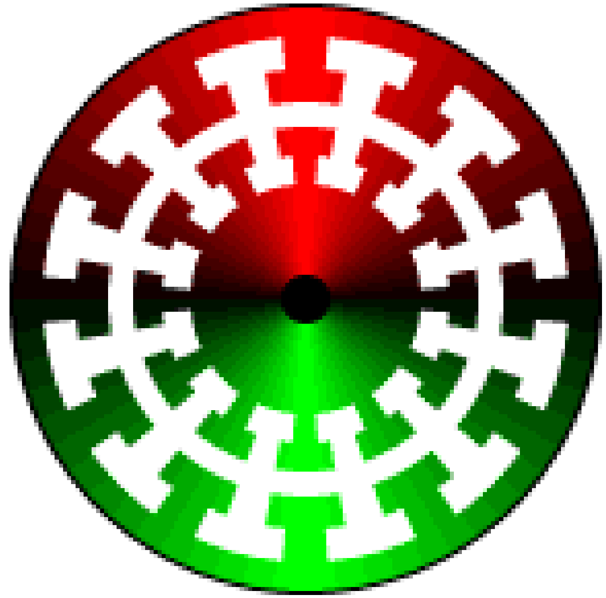
- A brushless ac motor is driven with ac sine wave voltages. The permanent magnet rotor rotates synchronous to the rotating magnetic field. The rotating magnetic field is illustrated using a red and green gradient. An actual simulation of the magnetic field would show a far more complex magnetic field.

AC Induction Motor



- The stator windings of an ac induction motor are distributed around the stator to produce a roughly sinusoidal distribution. When three phase ac voltages are applied to the stator windings, a rotating magnetic field is produced. The rotor of an induction motor also consists of windings or more often a copper squirrel cage imbedded within iron laminates. Only the iron laminates are shown. An electric current is induced in the rotor bars which also produce a magnetic field.

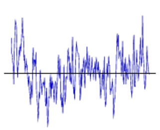
AC Induction Motor

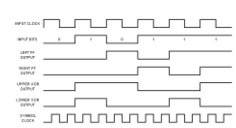


- The rotating magnetic field of the stator drags the rotor around. The rotor does not quite keep up with the the rotating magnetic field of the stator. It falls behind or slips as the field rotates. In this animation, for every time the magnetic field rotates, the rotor only makes three fourths of a turn. If you follow one of the bright green or red rotor teeth with the mouse, you will notice it change color as it falls behind the rotating field. The slip has been greatly exaggerated to enable visualization of this concept. A real induction motor only slips a few percent.

Huge List of Applications from Hurst

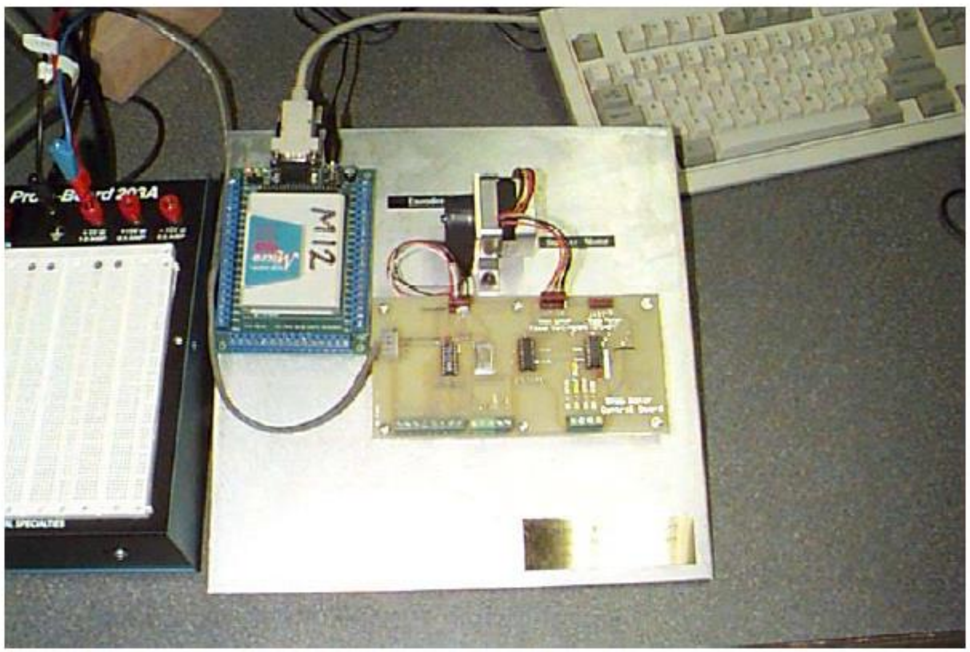
- Aircraft Window Polarizing Drives
- Antenna Positioning and Tuning Devices
- Audio/Video Recording Instruments
- Automated Inspection Equipment
- Automated Photo Developing Equipment
- Automated Photo Slide Trimming & Mounting Equipment
- Automatic Carton Marking & Dating Machines
- Automatic Dying and Textile Coloring Equipment
- Automatic Food Processing Equipment
- Automatic I.V. Dispensing Equipment
- Automatic Radio Station Identification Equipment
- Automotive
- Automotive Engine Pollution Analyzers
- Baseball Pitching Machine
- Blood Agitators
- Blood Cell Analyzer
- ……..
- Warning Light Flashers
- Railroad Signal Equipment
- Remote Focusing Microscopes
- Resonator Drives for Vibraphones
- ……..
- Silicone Wafer Production Equipment
- Solar Collector Devices
- Sonar Range Recorders and Simulators
- Steel Mill Process Scanners
- Tape Cleaning Equipment
- Tape Input for Automatic Typewriters
- Telescope Drives
- Ultrasonic Commercial Fish Detectors
- Ultrasonic Medical Diagnostic Equipment
- Voltage Regulators
- Water and Sewage Treatment Controls
- Weather Data Collection Machines
- Welding Machines
- X-Ray Equipment
- XY Plotters



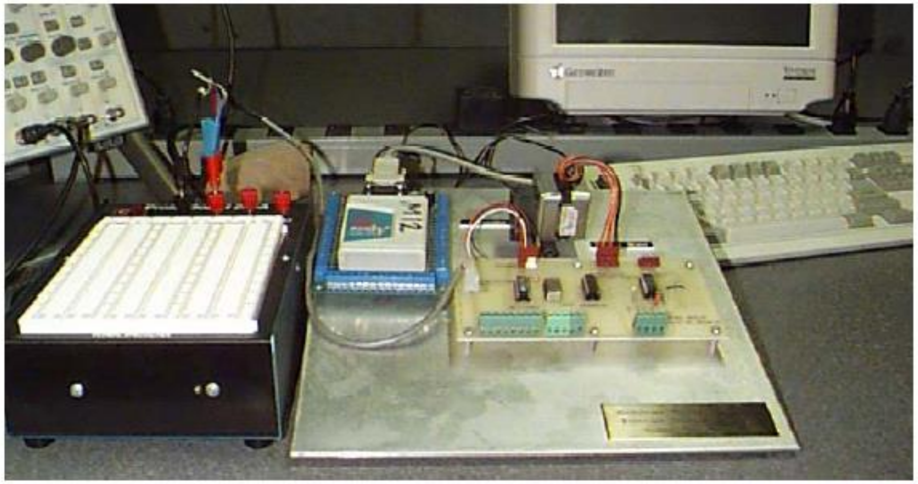


Stepper Motor from Mechatronics

Stepper Motor
Open-Loop and Closed-Loop Control



- stepper motor
- optical encoder
- microcontroller
- electronics to interface the microcontroller to the motor and encoder
- full-step and half-step operation
- control via a Quad-Darlington IC
- control via a step-motor-driver IC
- programming in Basic or C



Stepper Motor System Design: Ink-Jet Printer Application

Stepper Motor Open-Loop and Closed-Loop Control