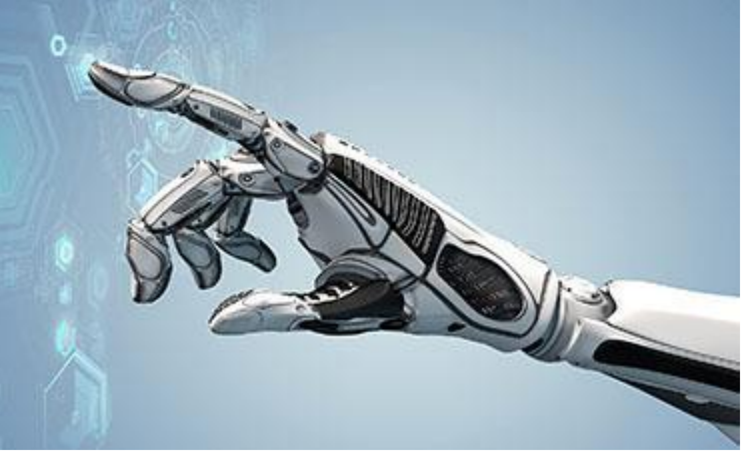


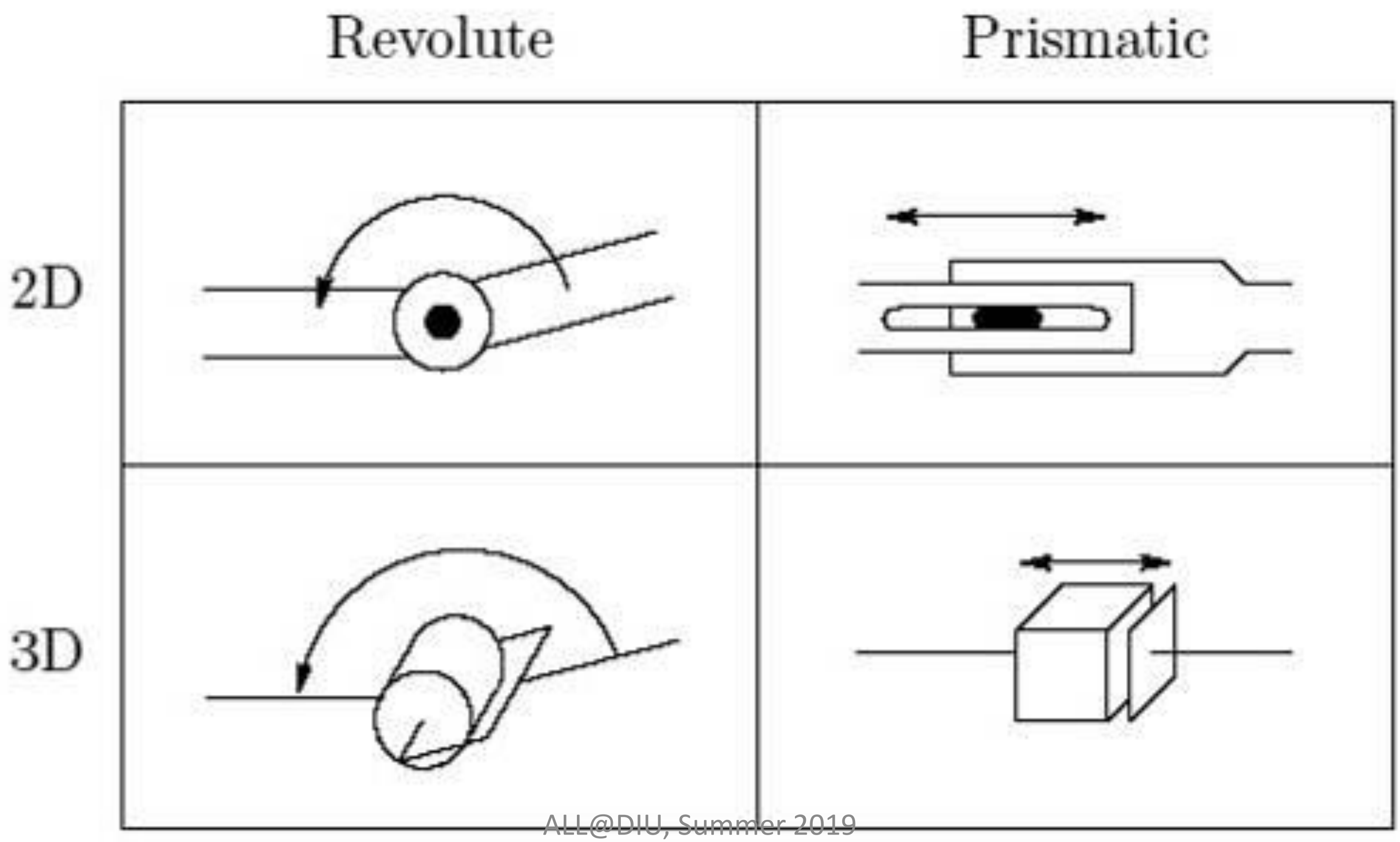
CSE426: Principles of Robotics

Lesson 8: Working with Actuators

Robot Joints

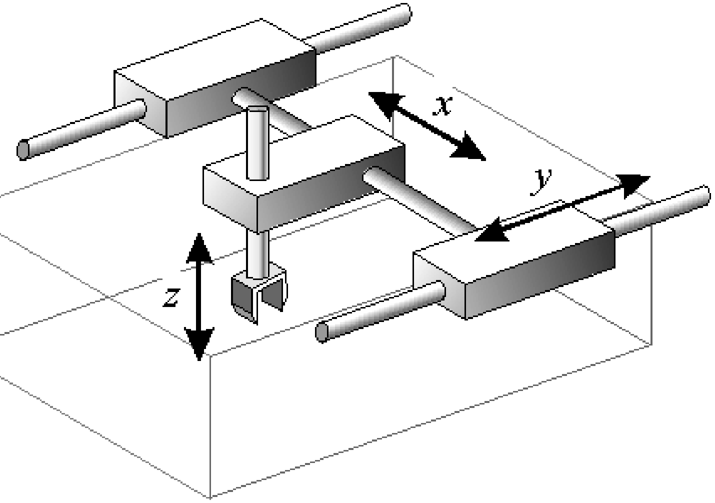
Robot Joints

- Robot joints can be either **rotary** (also known as revolute) or **prismatic** (telescoping)

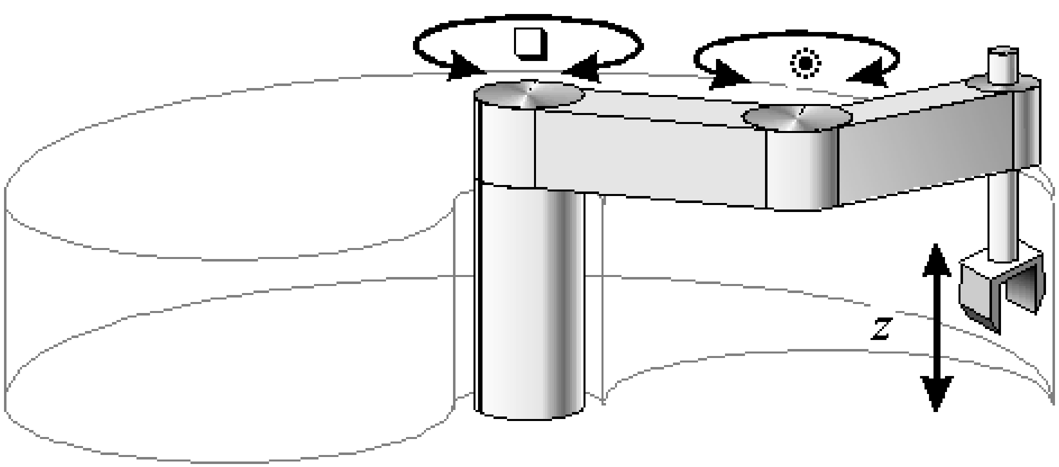


Robot Joints (cont…)

•Prismatic Cartesian robot



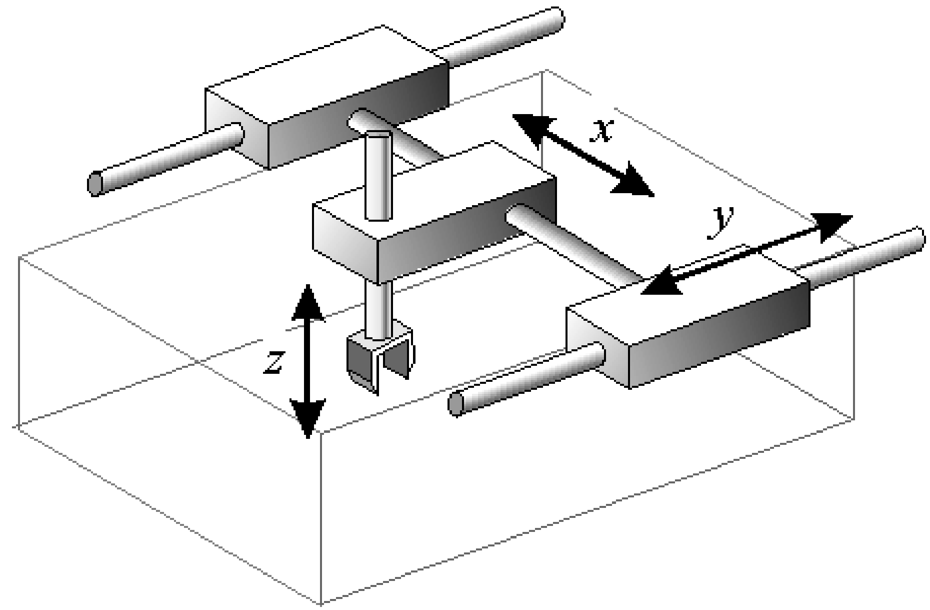
- Actuators are used in order to produce mechanical movement in robots.

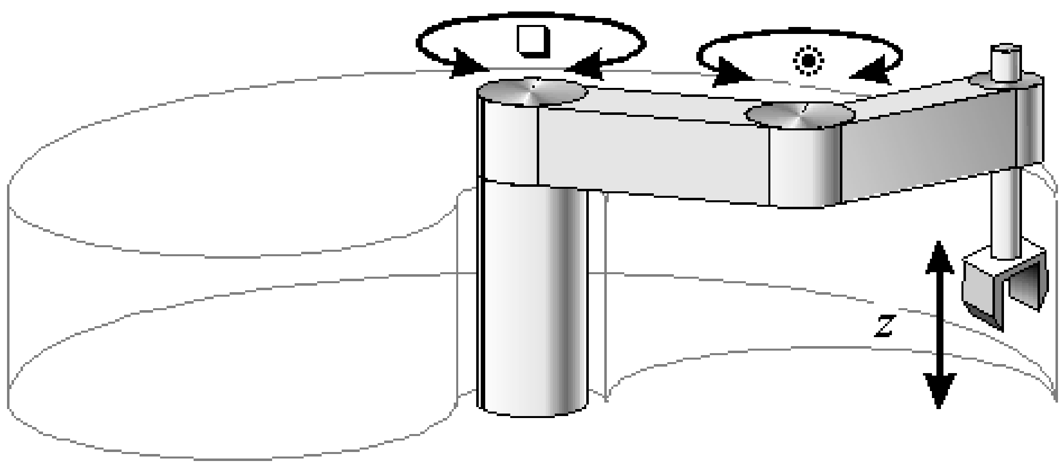


Rotary SCARA robot

Robot Joints (cont...)

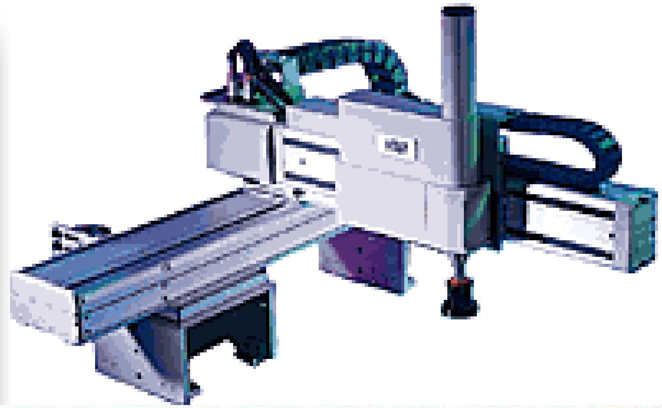
Prismatic Cartesian robot

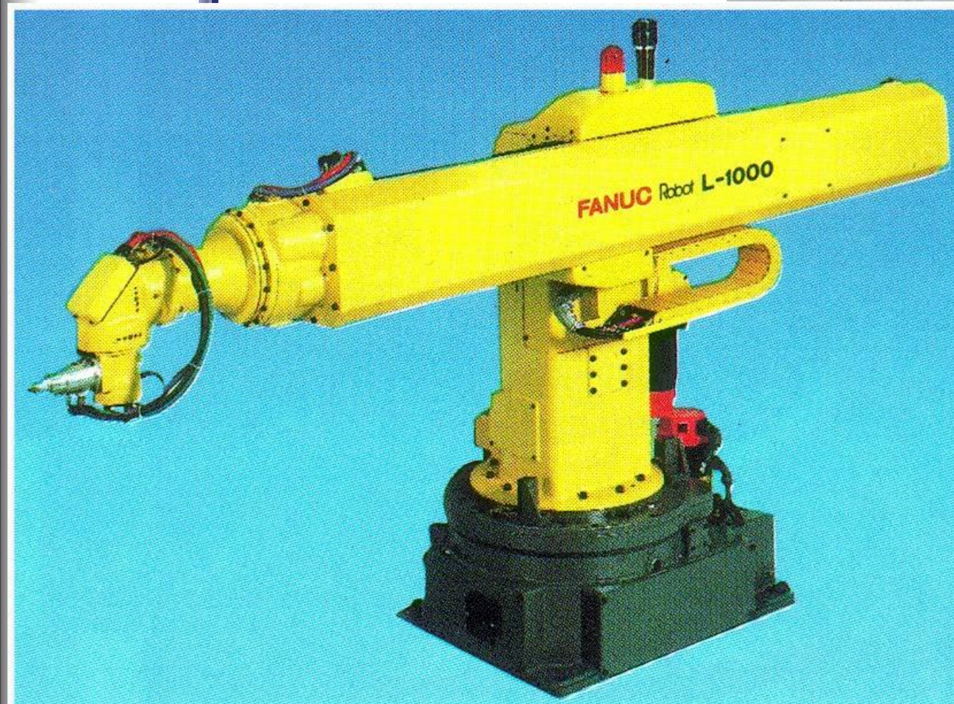




Rotary SCARA robot

Robot Joints (cont…)





Actuator Control

1. Robots are classified by control method into **servo** and **non-servo** robots

2. *Non-servo robots* are essentially open-loop devices whose movements are limited to predetermined mechanical stops

3. Servo robots use closed-loop computer control to determine their motion

Types of Actuators

1. Some of the most common actuators are:

    1. **Electric motors**, the most common actuators in mobile robots, used both to provide location by powering wheels or legs, and for manipulation by actuating robot arms

    2. **Artificial muscles** of various types, none of which are very good approximations of living muscles

    3. **Pneumatic** and **hydraulic** actuators, used in industry for large manipulation tasks but seldom for mobile robots

Actuators and motors

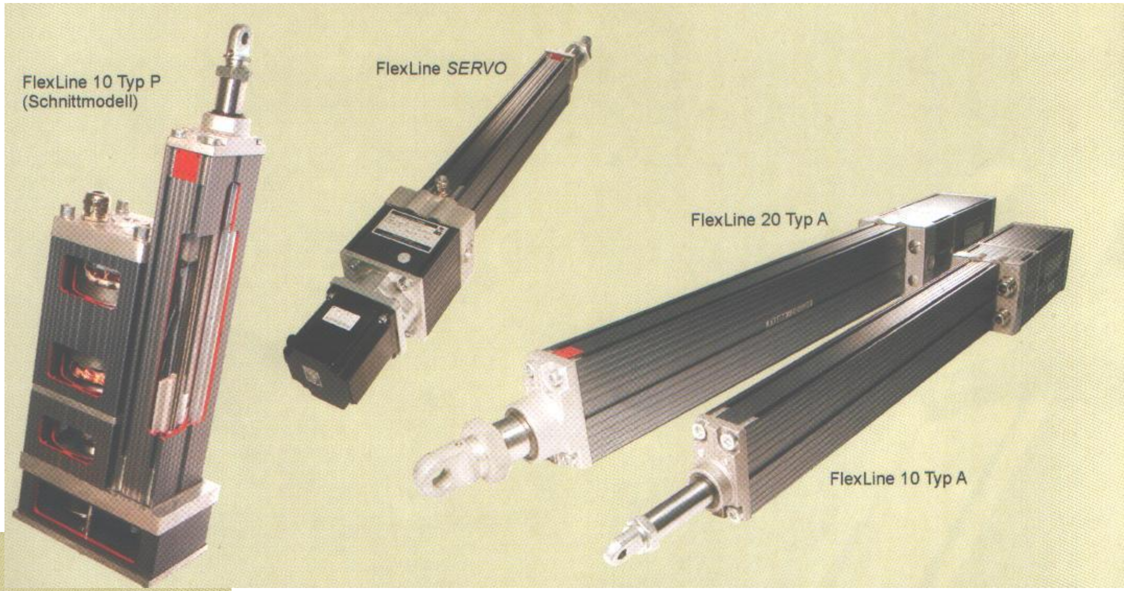
- Most actuators convert electrical energy into mechanical energy through the use of electromagnetic fields and rotating wire coils.
- When a voltage is applied to a motor, it outputs a fixed amount of mechanical power
    - (usually to a shaft, gear, and/or wheel),
    - spinning at some speed
    - with some amount of torque.

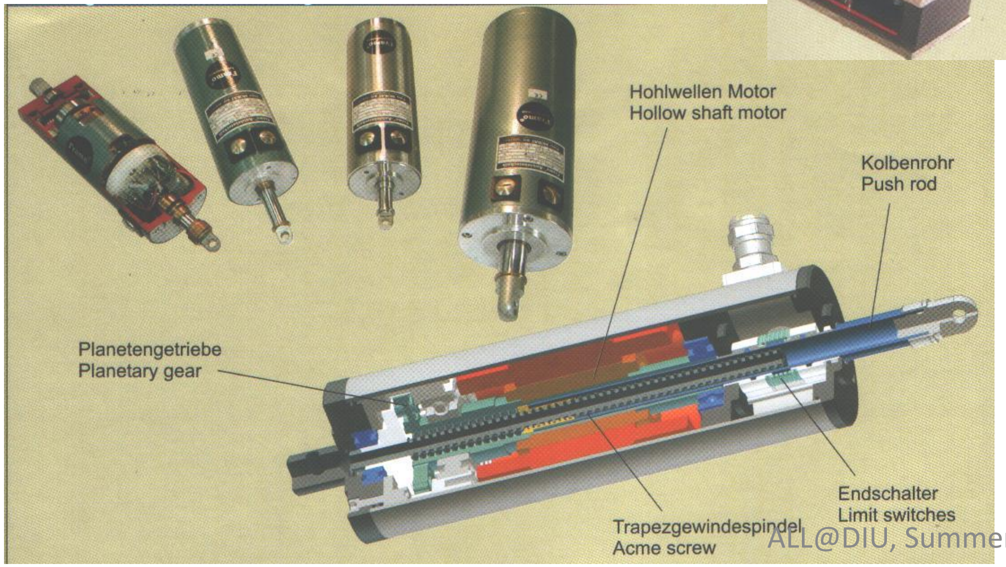
Electric Motors

Electric actuators

•Mainly rotating but also linear ones are available

•linear movement with gear or with real linear motor





Electrical Actuator Types

- DC-motors
- brushless DC-motors
- asynchronous motors
- synchronous motors
- reluctance motors (stepper motors)

Not discussed

Electric Motors

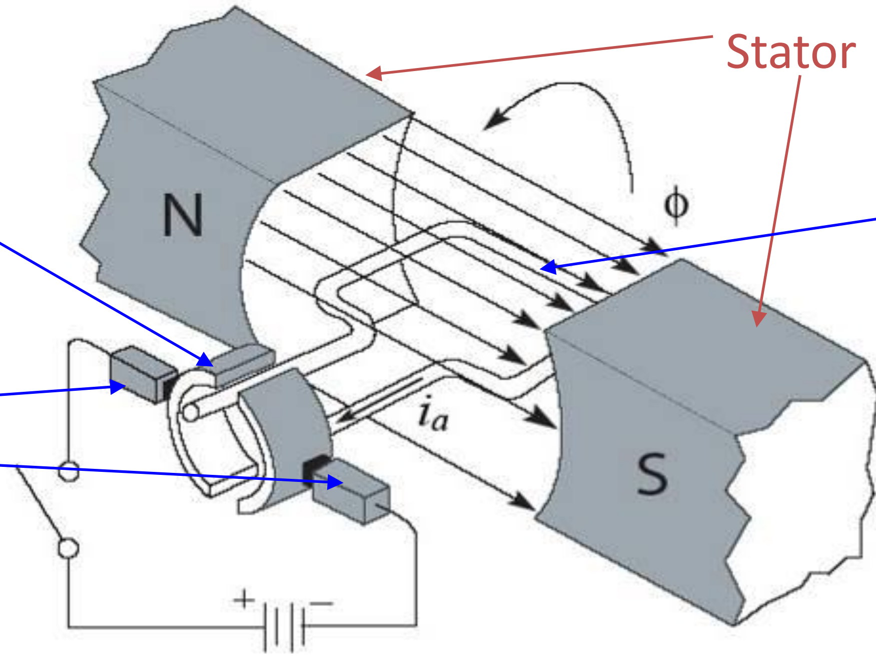
1. Electric motors are the most common source of torque for mobility and/or manipulation in robotics

2. The physical principle of all electric motors is that when an electric current is passed through a conductor (usually a coil of wire) placed within a magnetic field, a force is exerted on the wire causing it to move

How Do Electric Motors Work?

Components Of An Electric Motor

- The principle components of an electric motor are:
  1. North and south **magnetic poles** to provide a strong magnetic field.
     1. Being made of bulky ferrous material they traditionally form the outer casing of the motor and collectively form the **stator**
  2. An **armature**, which is a cylindrical ferrous core rotating within the stator and carries a large number of windings made from one or more conductors

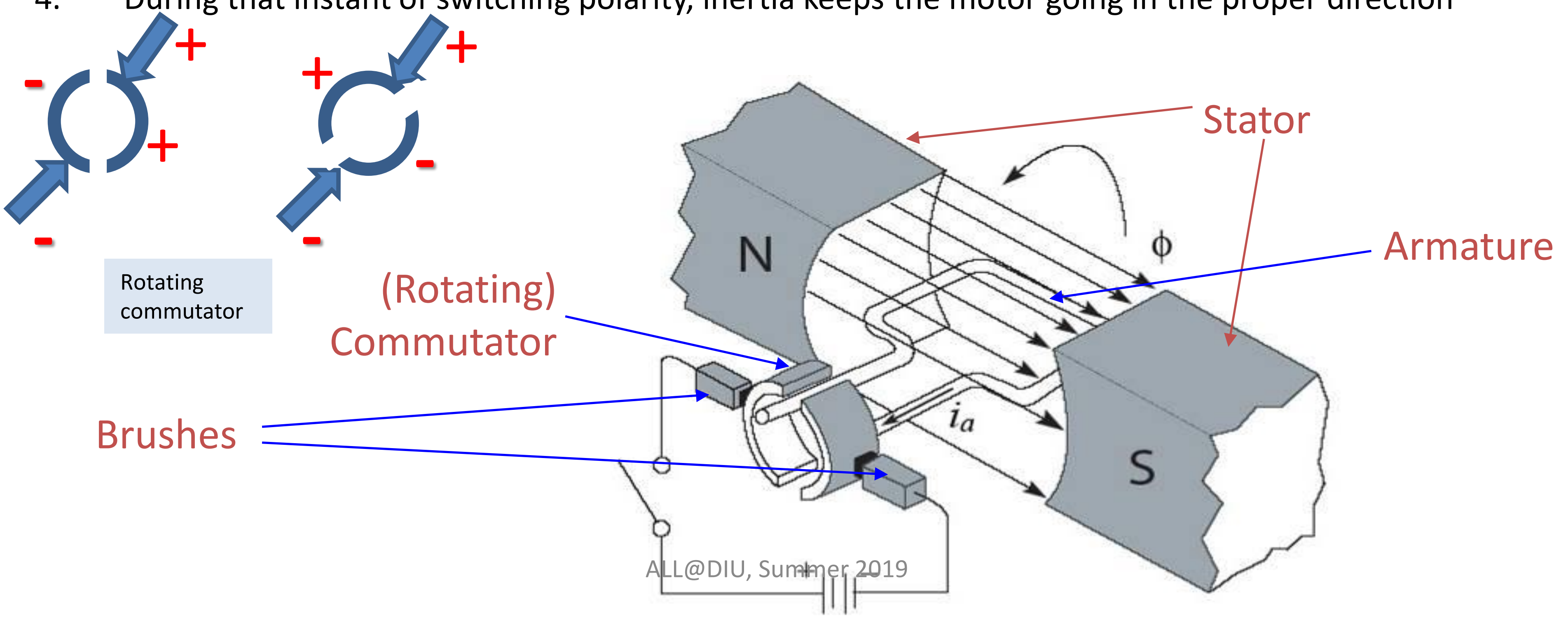


Brushes in fixed positions and in contact with the rotating commutator contacts. They carry direct current to the coils, resulting in the required motion

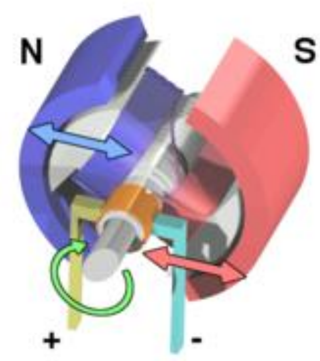
A **commutator**, which *rotates with the armature* and consists of copper contacts attached to the end of the windings

How Do Electric Motors Work?

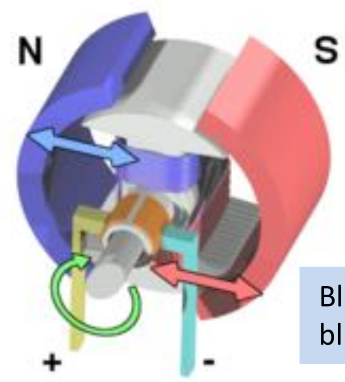
1. The classic DC motor has a rotating armature in the form of an electromagnet
2. **A rotary switch called a commutator** reverses the direction of the electric current twice every cycle, to flow through the armature so that the poles of the electromagnet push and pull against the permanent magnets on the outside of the motor
3. As the poles of the armature electromagnet pass the poles of the permanent magnets, the commutator reverses the polarity of the armature electromagnet.
4. During that instant of switching polarity, inertia keeps the motor going in the proper direction



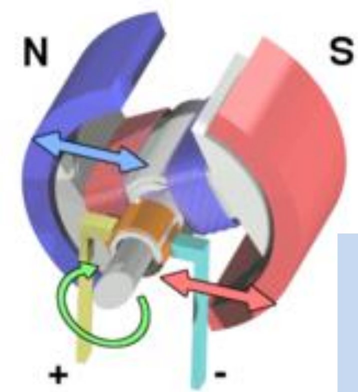
How Do Electric Motors Work? (cont…)



Blue in armature near blue in stator



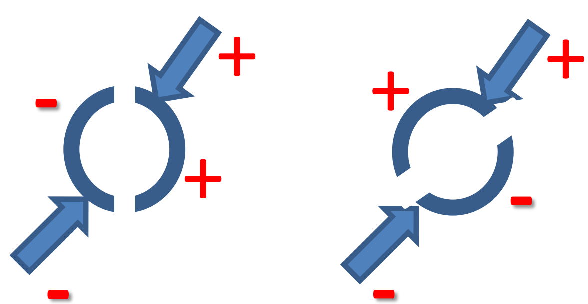
Blue between blue and red



Blue near red, because of commutator rotation

1. A simple DC electric motor: when the coil is powered, a magnetic field is generated around the armature.
2. The left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation

The armature continues to rotate



Rotating commutator

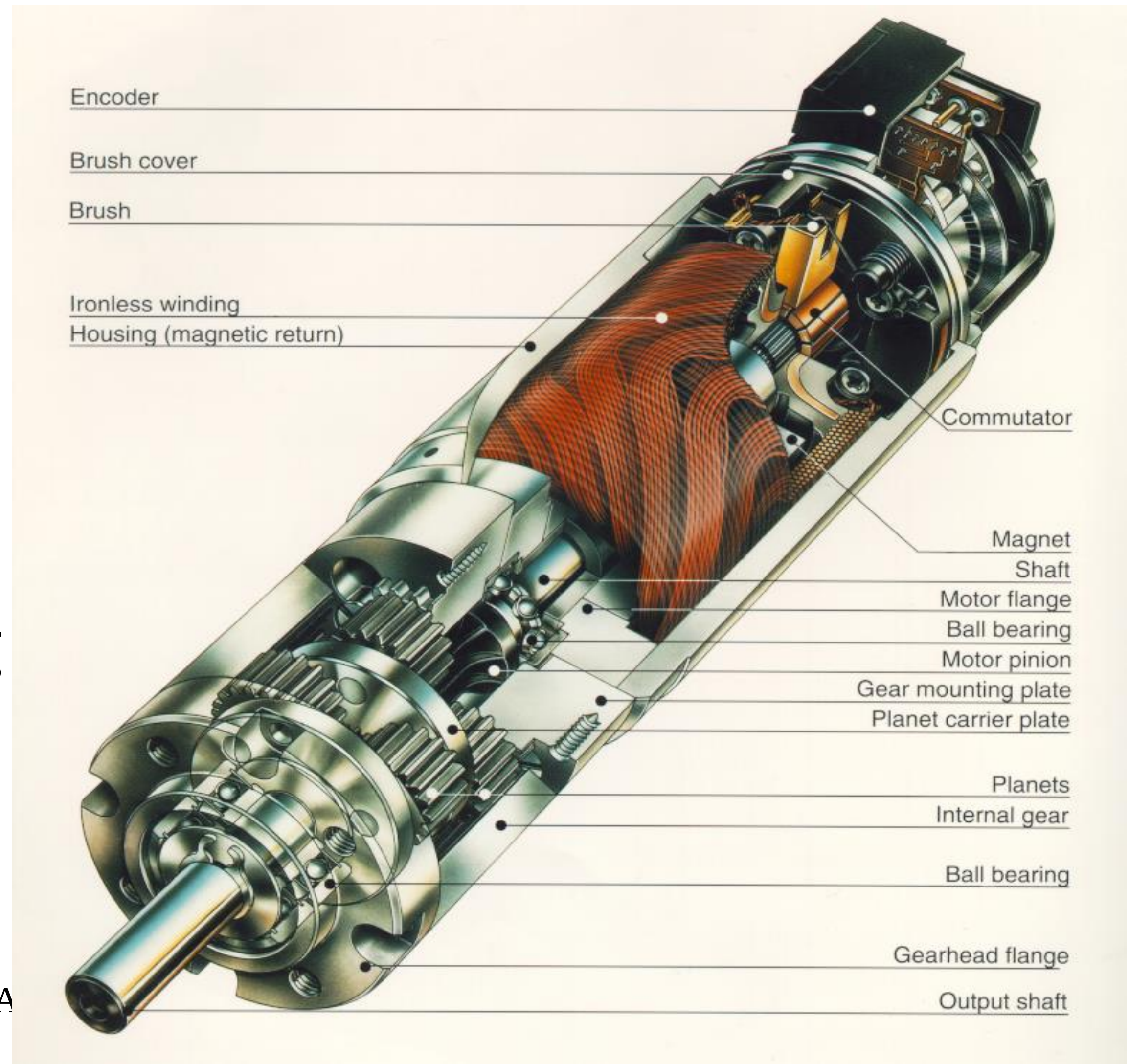
- When the armature becomes *horizontally aligned*, the commutator reverses the direction of current through the coil, ***reversing the magnetic field***.
- The process then repeats.

Application of Electric Motors

1. Electric motors usually have a small rating, ranging up to a few horsepower
2. They are used in small appliances, battery operated vehicles, for medical purposes and in other medical equipment like x-ray machines
3. Electric motors are also used in toys, and in automobiles as auxiliary motors
   - for the purposes of seat adjustment, power windows, sunroof, mirror adjustment, blower motors, engine cooling fans and the like

High quality DC-Motors

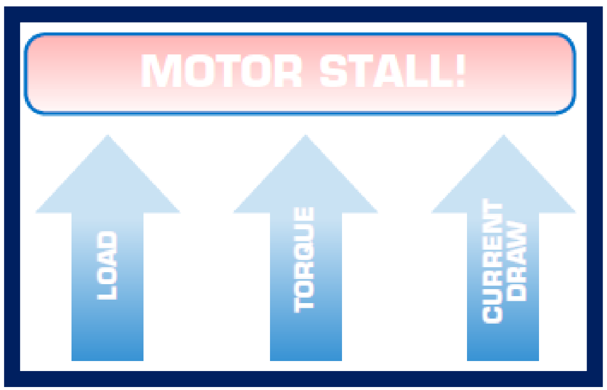
- Not cheap
- easy to control
- 1W - 1kW
- can be overloaded
- brushes wear
- limited overloading on high speeds



Motor Loading

- Motors apply torque in response to loading
- **Motor Loading** happens when there is any opposing force (such as friction or a heavy mass) acting as a load and requiring the motor to ***output torque to overcome it.***
- The higher the load placed on a motor output, the more the motor will "fight back" with an opposing torque.
- However, since the motor outputs a fixed amount of power, the more torque the motor outputs, the slower its rotational speed.

Motor applies torque to overcome the friction of a wheel turning against the ground



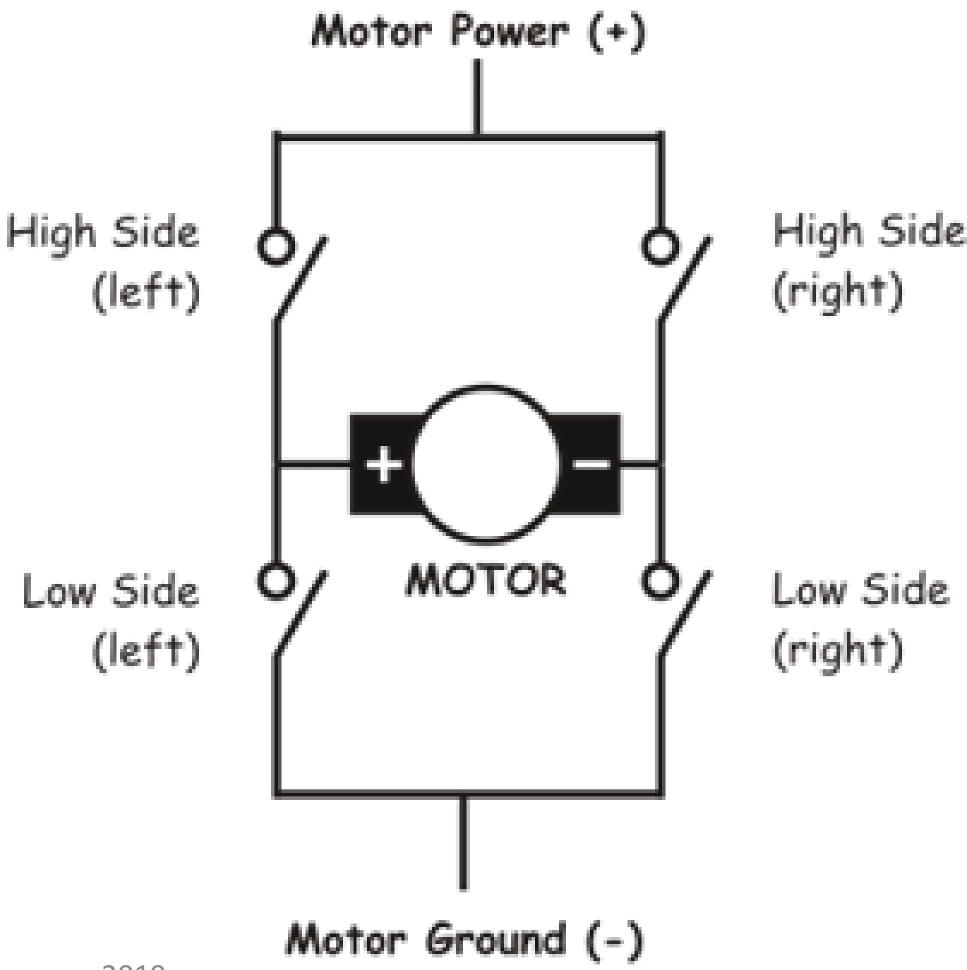
REMEMBER THAT MOTORS STALL. DO NOT DAMAGE THE SERVOS!!

If you keep increasing the load on a motor, the motor eventually stops spinning or **stalls**.

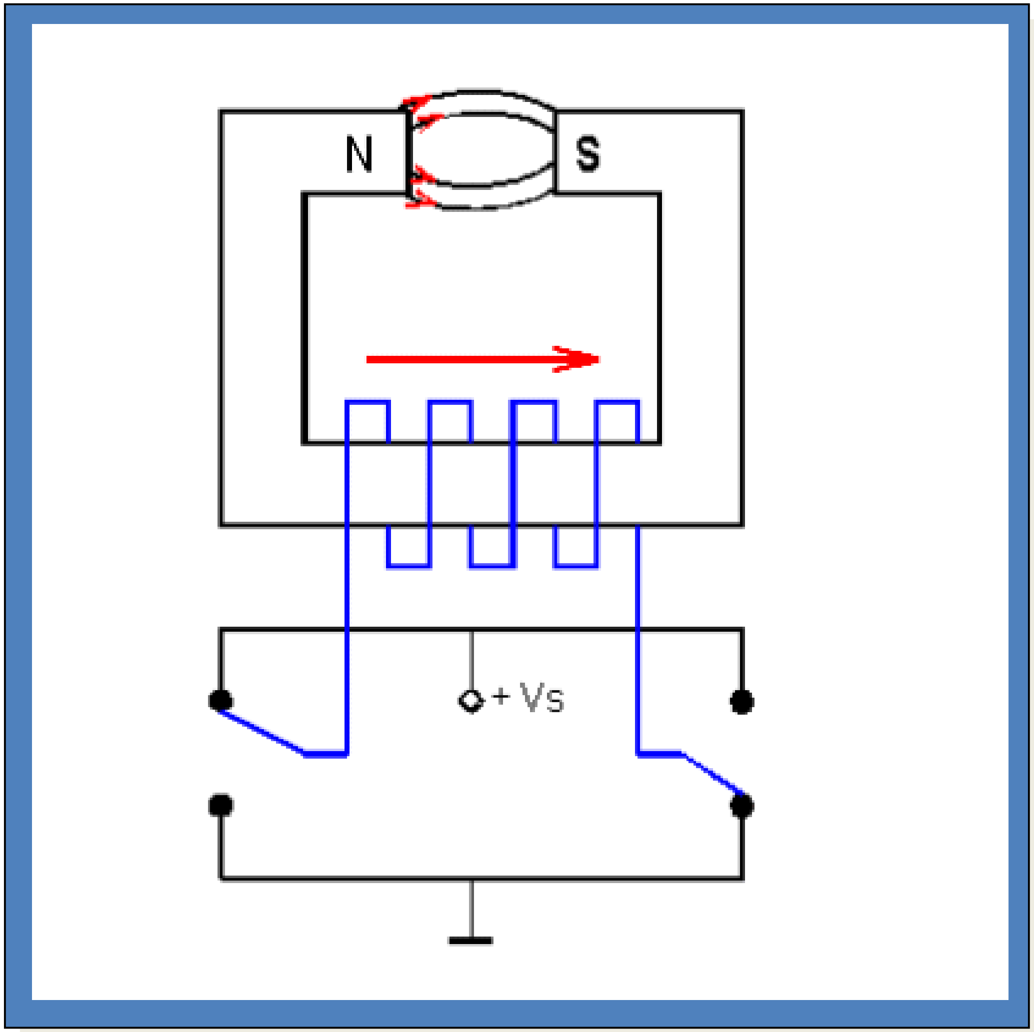
- A DC Motor draws a certain amount of electrical current (measured in amps) depending on how much load is placed on it.
- As the load increases on the motor, the more torque the motor outputs to overcome it and the more current the motor draws.

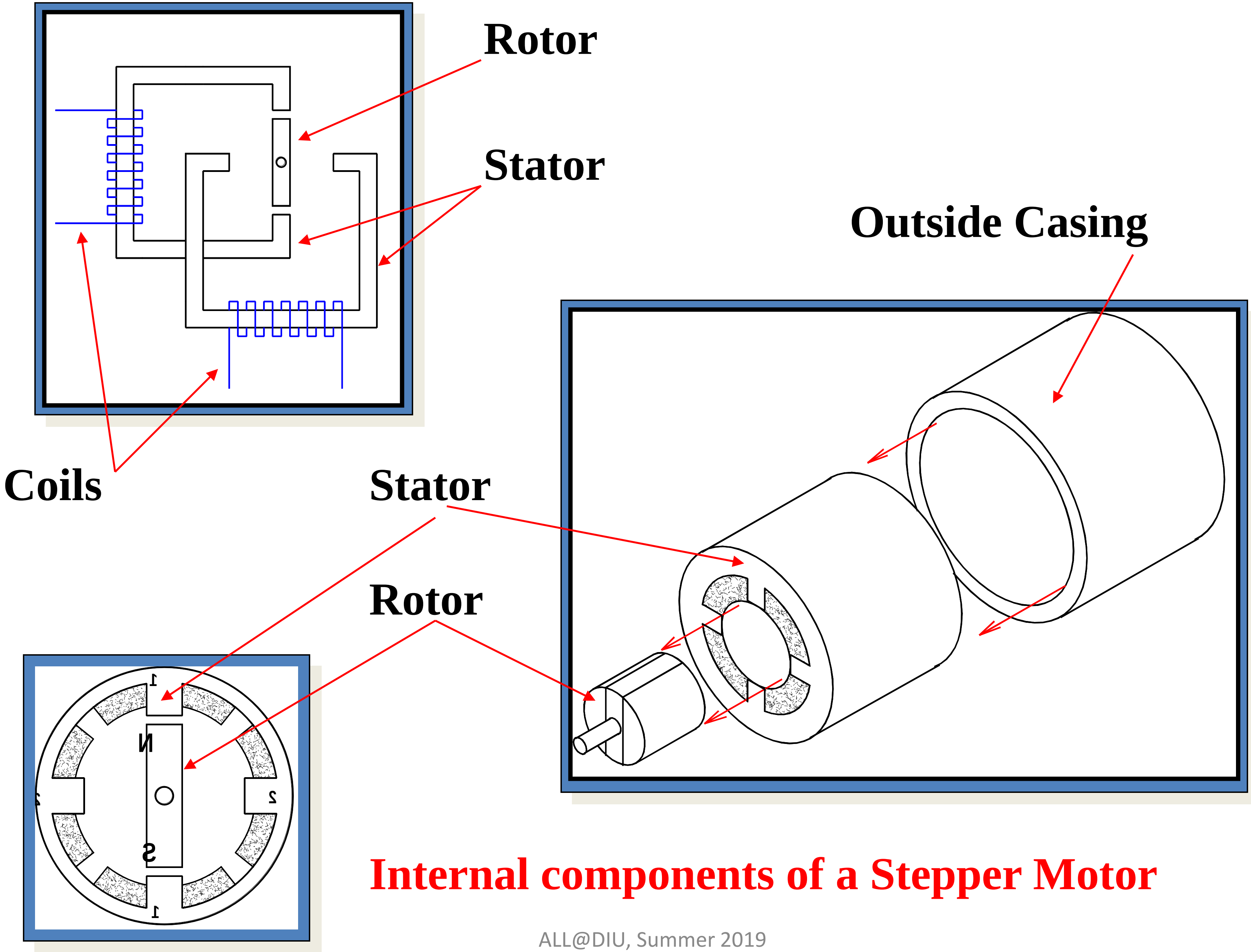
DC-motor control

- Controller + H-bridge
- PWM-control
- Speed control by controlling motor current=torque
- Efficient small components
- PID control



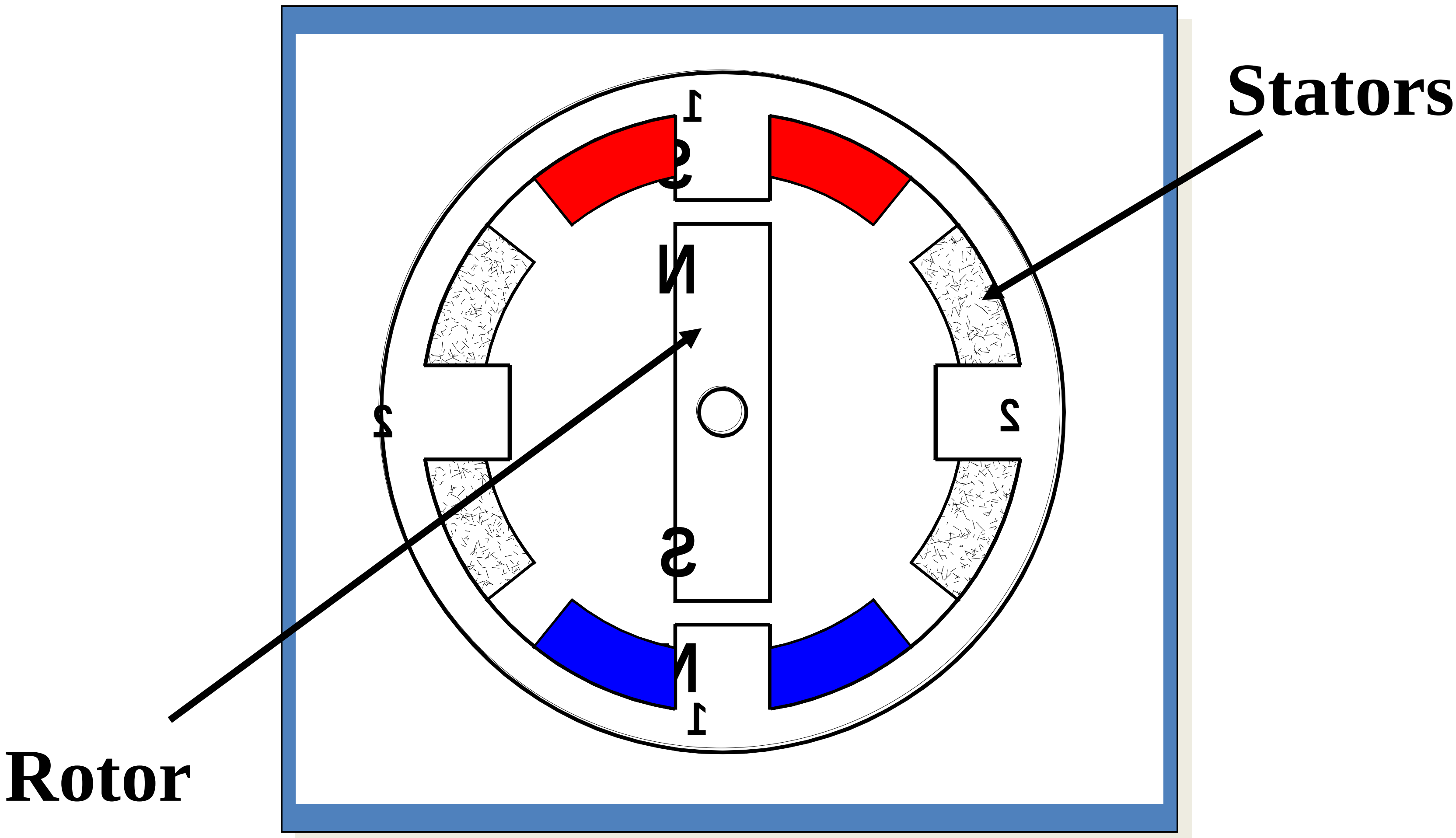
Stepper Motor / Electro magnet



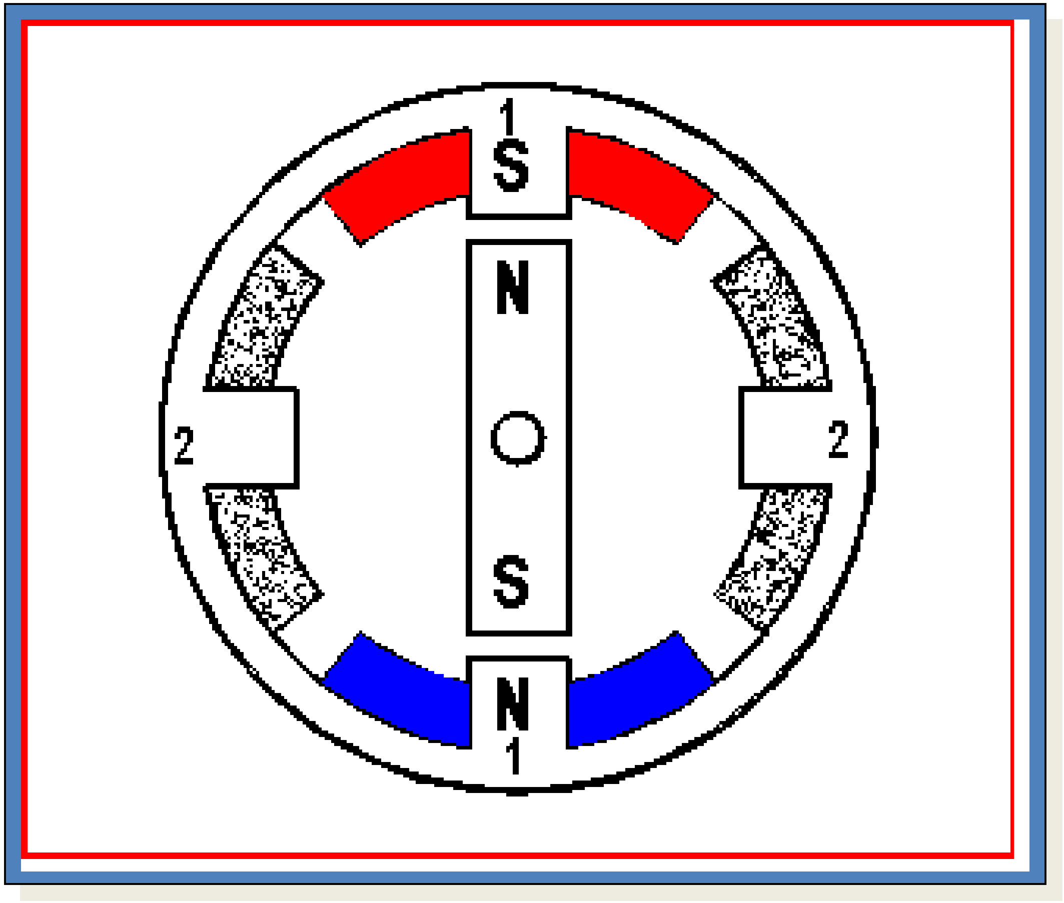


Internal components of a Stepper Motor

Cross Section of a Stepper Motor

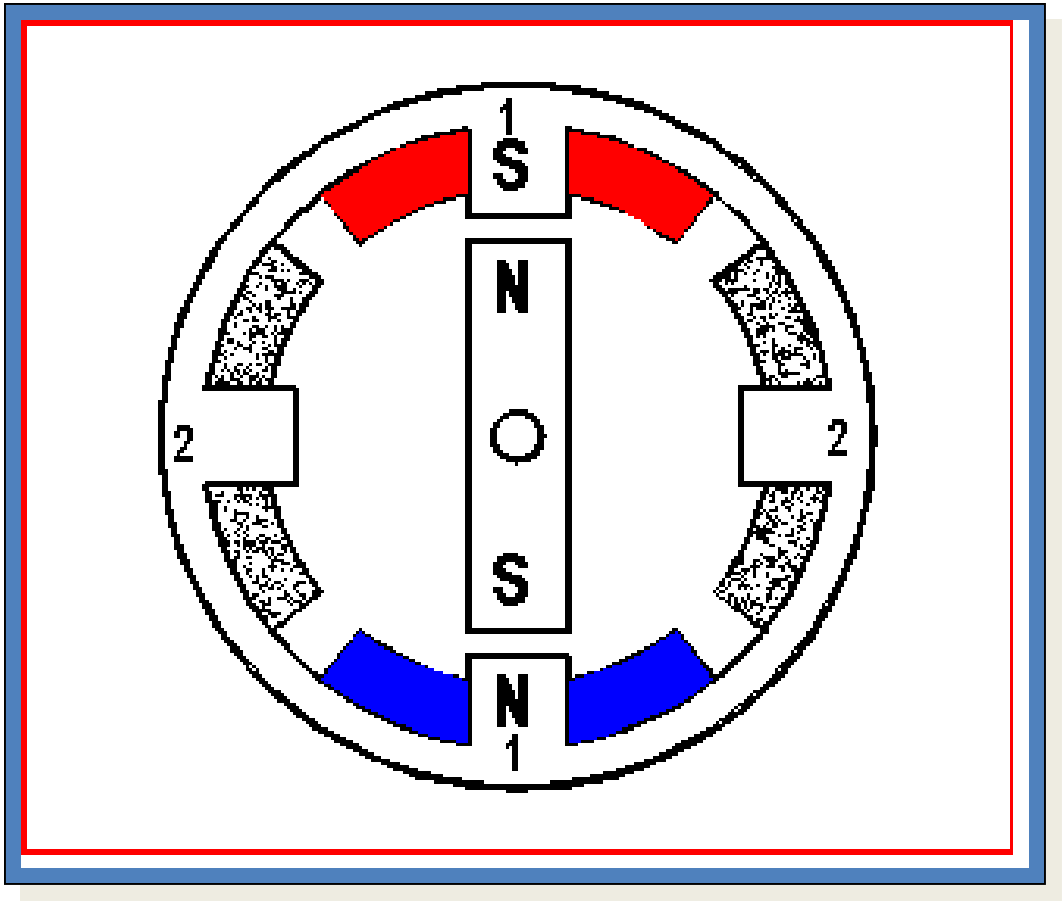


Full Step Operation

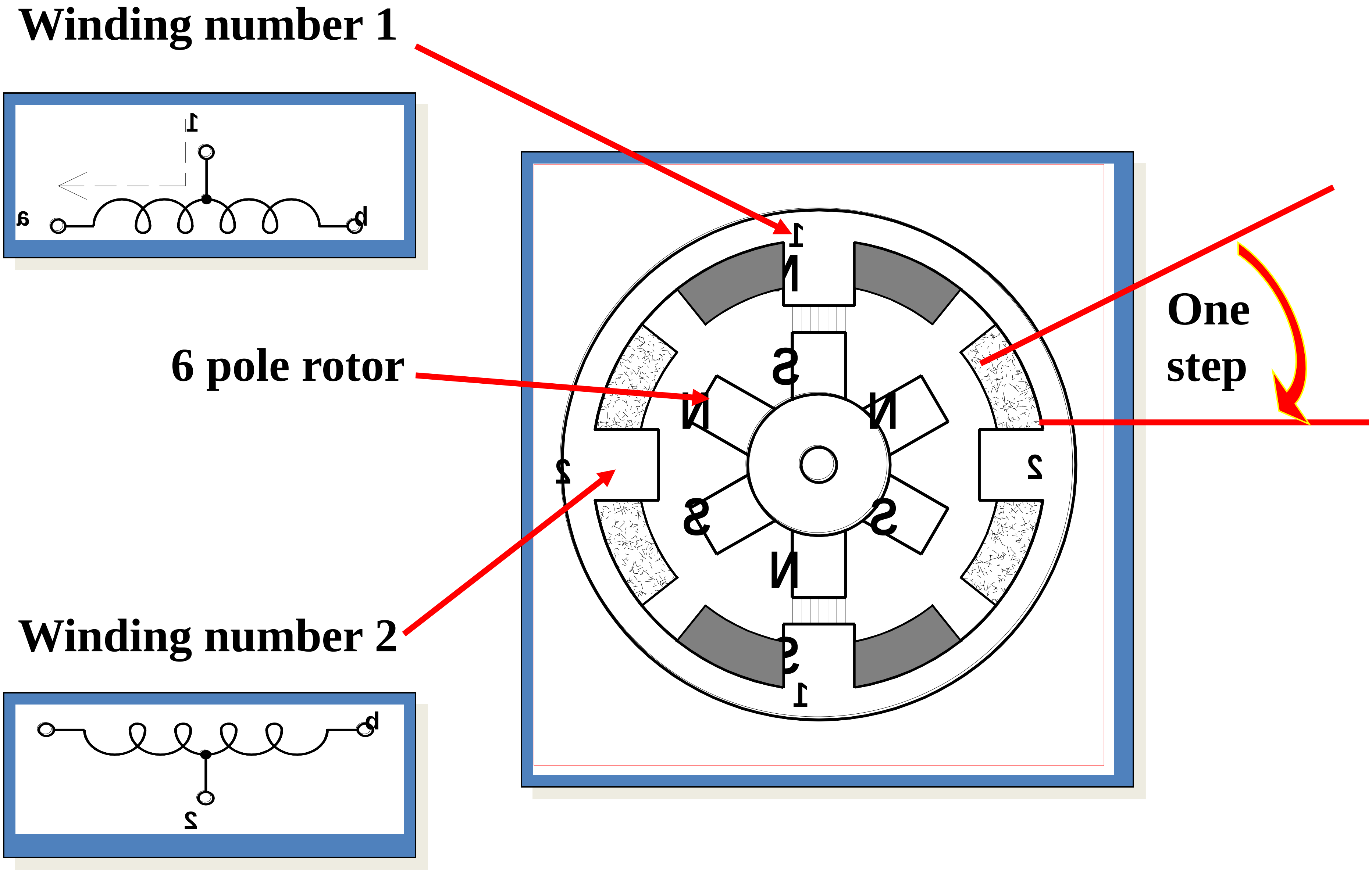


Four Steps per revolution i.e. 90 deg. steps.

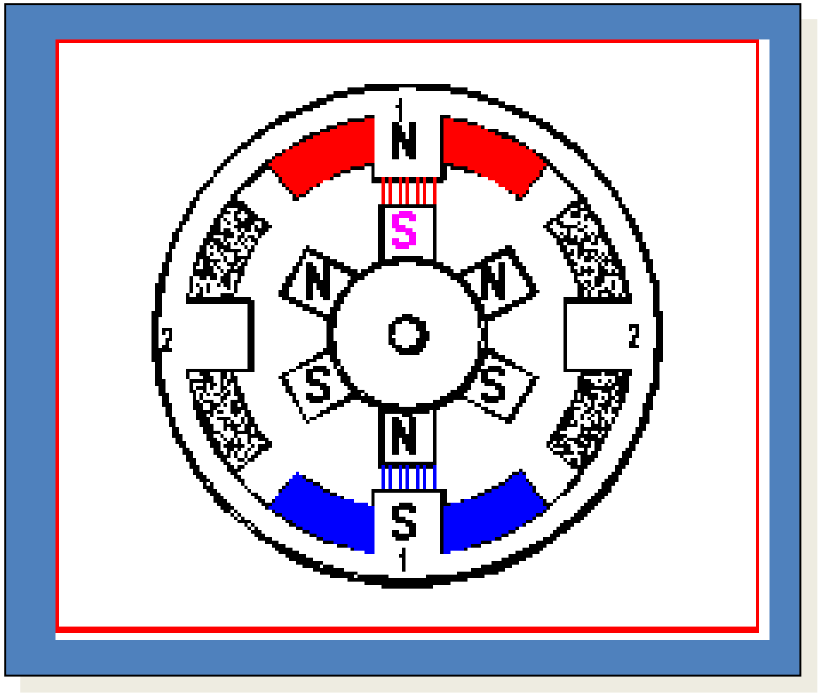
Half Step Operation



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

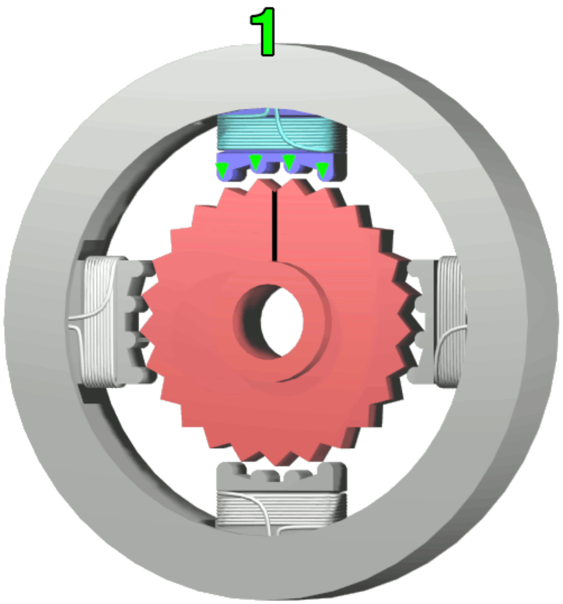

Winding number 1
6 pole rotor
One step
Winding number 2

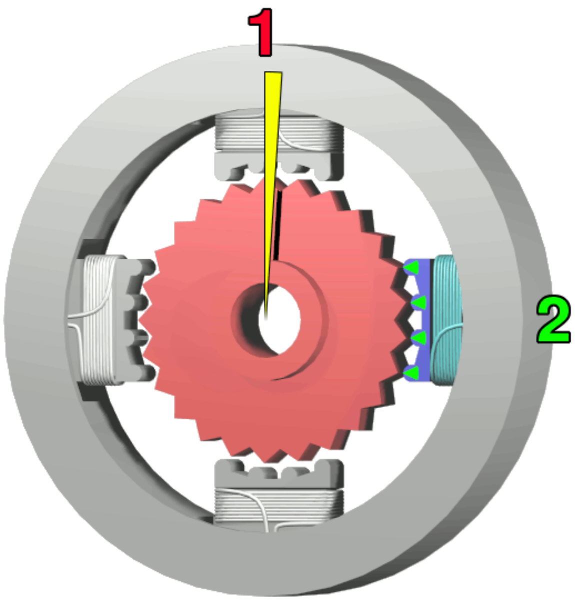
Six pole rotor, two electro magnets.



How many steps are required for one complete revolution?

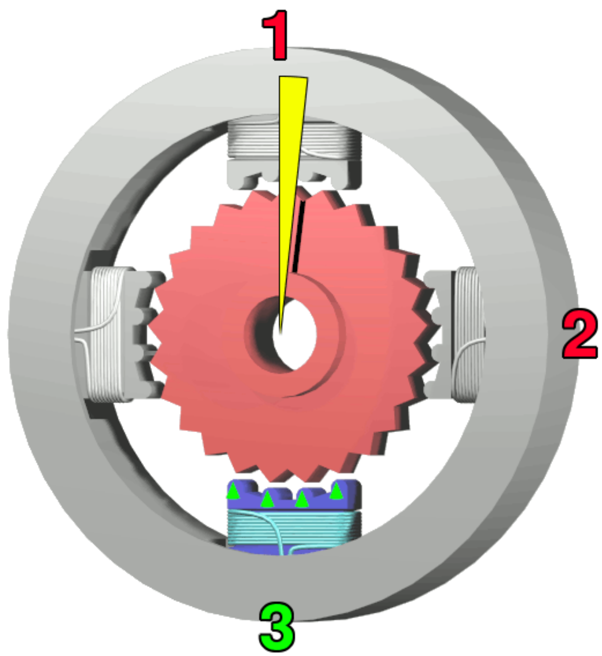
Practical Stepper motor operation



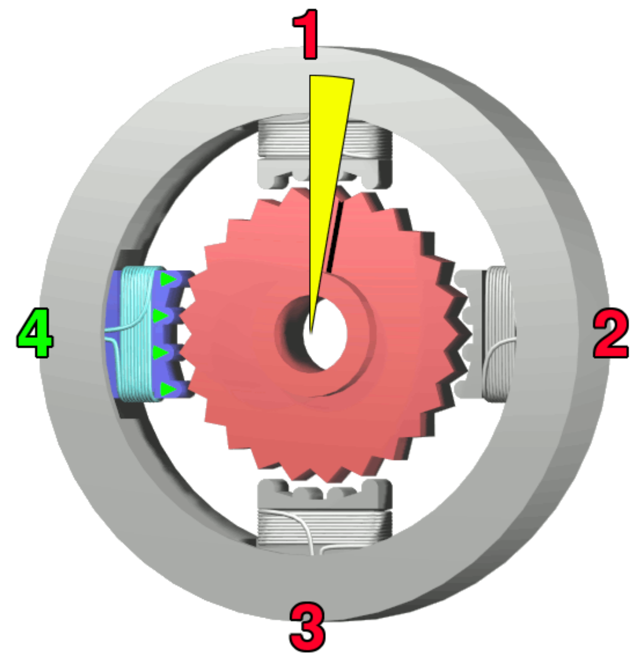


The top electromagnet (1) is turned on, attracting the nearest teeth of a gear-shaped iron rotor. With the teeth aligned to electromagnet 1, they will be slightly offset from electromagnet 2

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.

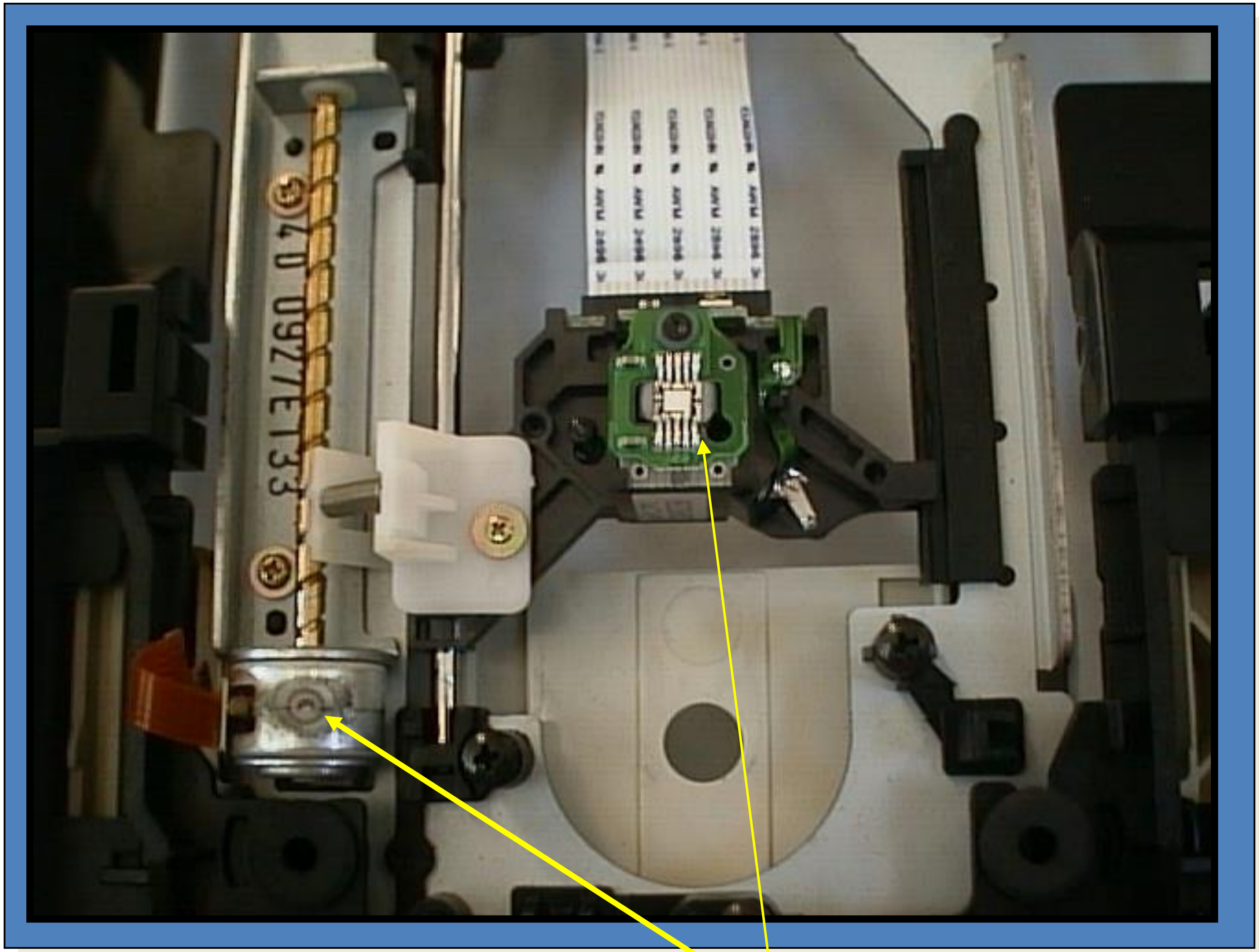


The bottom electromagnet (3) is energized; another 3.6° rotation occurs.



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.

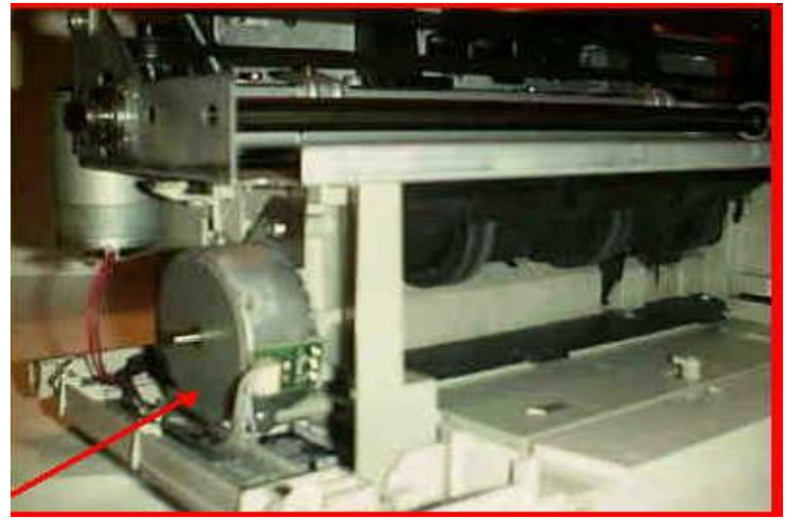
Stepper motor applications



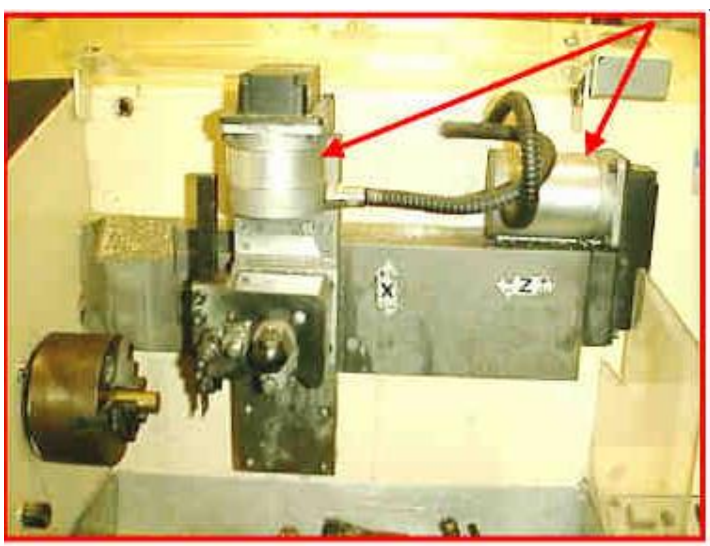
Stepping Motor to move read-write head

Stepper motor applications

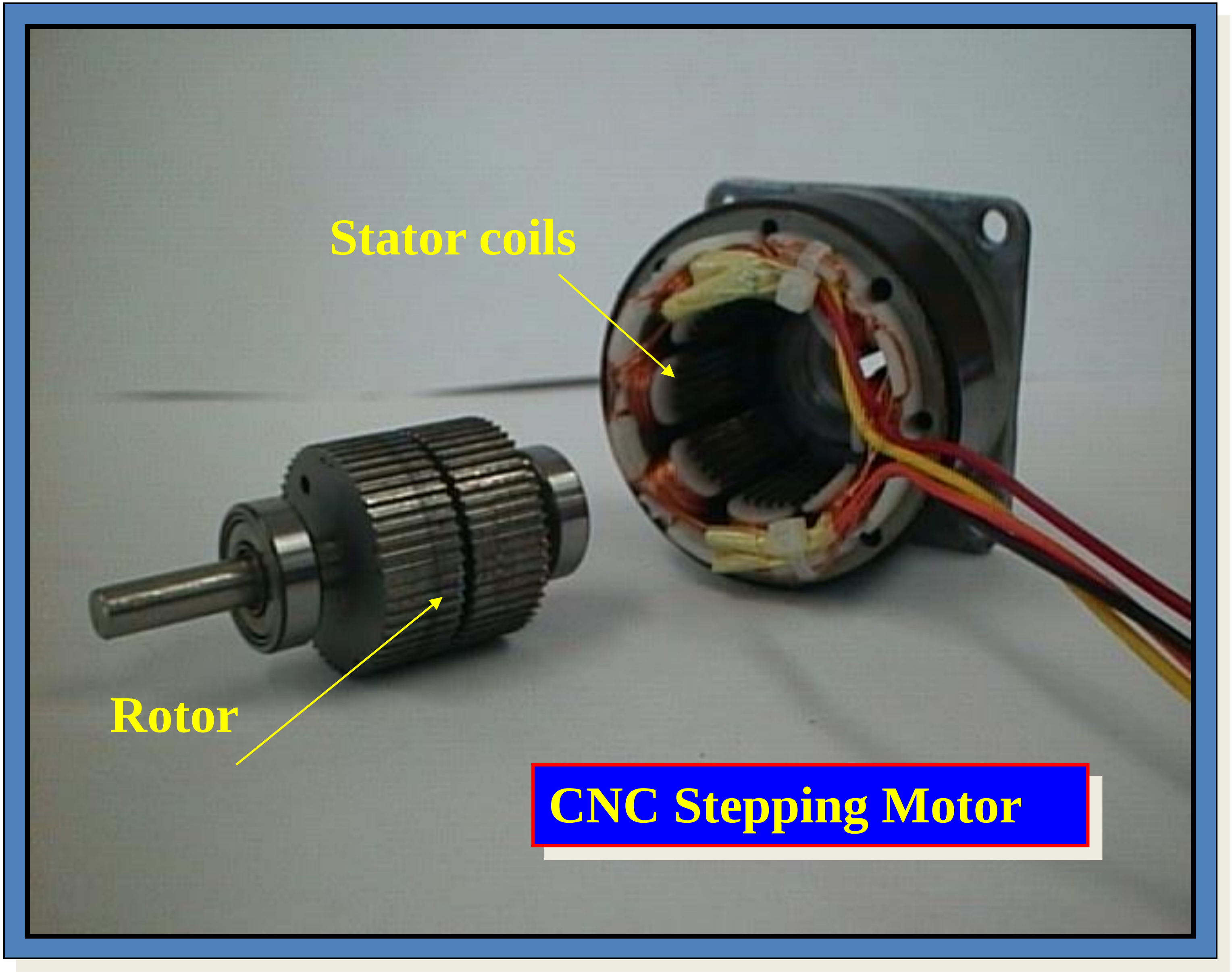
Paper feeder on printers



Stepper motors



CNC lathes


Stator coils
Rotor
CNC Stepping Motor

Advantages / Disadvantages

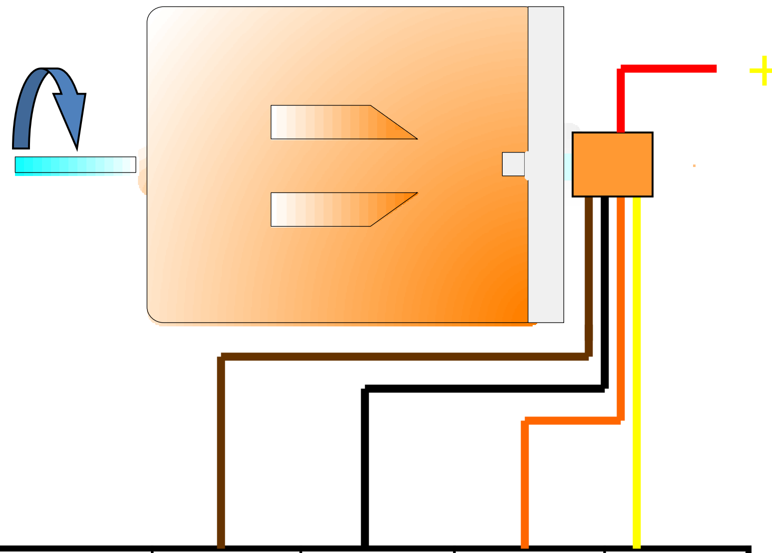
Advantages:-

- 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

Stepper Motors

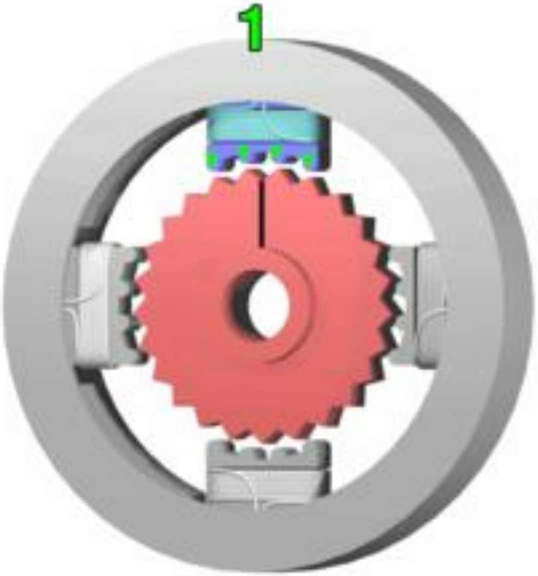
When incremental rotary motion is required in a robot, it is possible to use **stepper motors**

A stepper motor possesses the ability to move a specified number of revolutions or fraction of a revolution in order to achieve a fixed and consistent angular movement

This is achieved by increasing the numbers of poles on both rotor and stator

Additionally, soft magnetic material with many teeth on the rotor and stator cheaply multiplies the number of poles (reluctance motor)

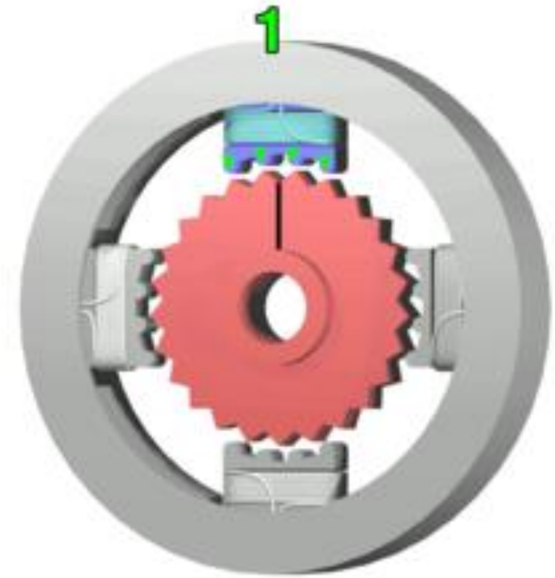
Stepper Motors



This figure illustrates the design of a stepper motor, arranged with four magnetic poles arranged around a central rotor

Note that the teeth on the rotor have a slightly tighter spacing to those on the stator, this ensures that the two sets of teeth are close to each other but not quite aligned throughout

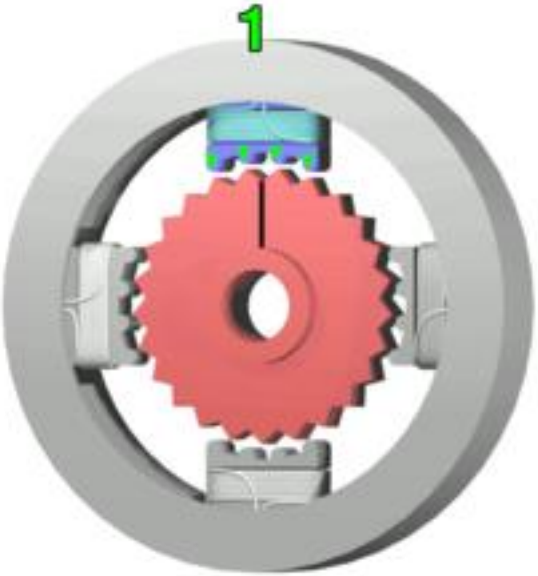
Stepper Motors (cont…)



Movement is achieved when power is applied for short periods to successive magnets

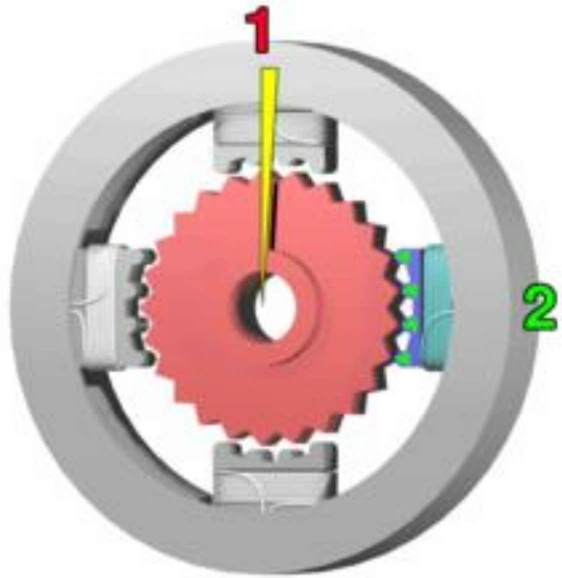
Where pairs of teeth are least offset, the electromagnetic pulse causes alignment and a small rotation is achieved, typically 1-2^{o}

How Does A Stepper Motor Work?



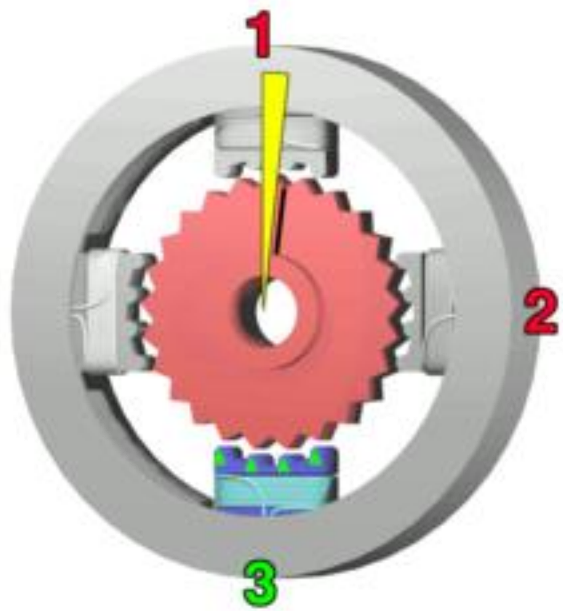
The top electromagnet (1) is charged, attracting the topmost four teeth of a sprocket.

How Does A Stepper Motor Work? (cont…)



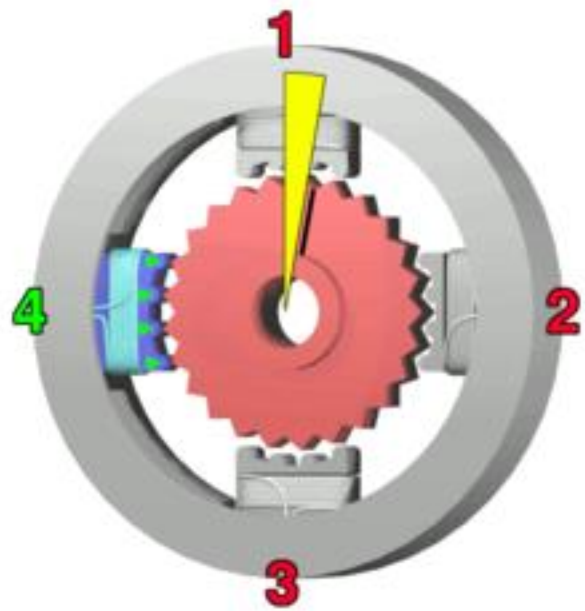
The top electromagnet (1) is turned off, and the right electromagnet (2) is charged, pulling the nearest four teeth to the right. This results in a rotation of 3.6°

How Does A Stepper Motor Work? (cont…)



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

How Does A Stepper Motor Work? (cont…)



The left electromagnet (4) is enabled, rotating again by 3.6°. When the top electromagnet (1) is again charged, 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.

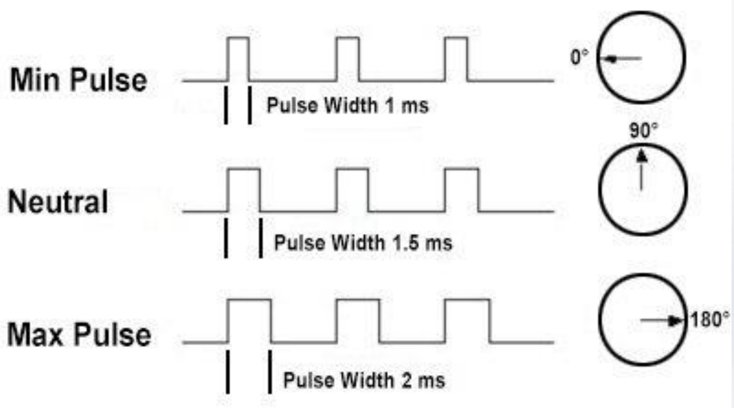
Stepper Motor

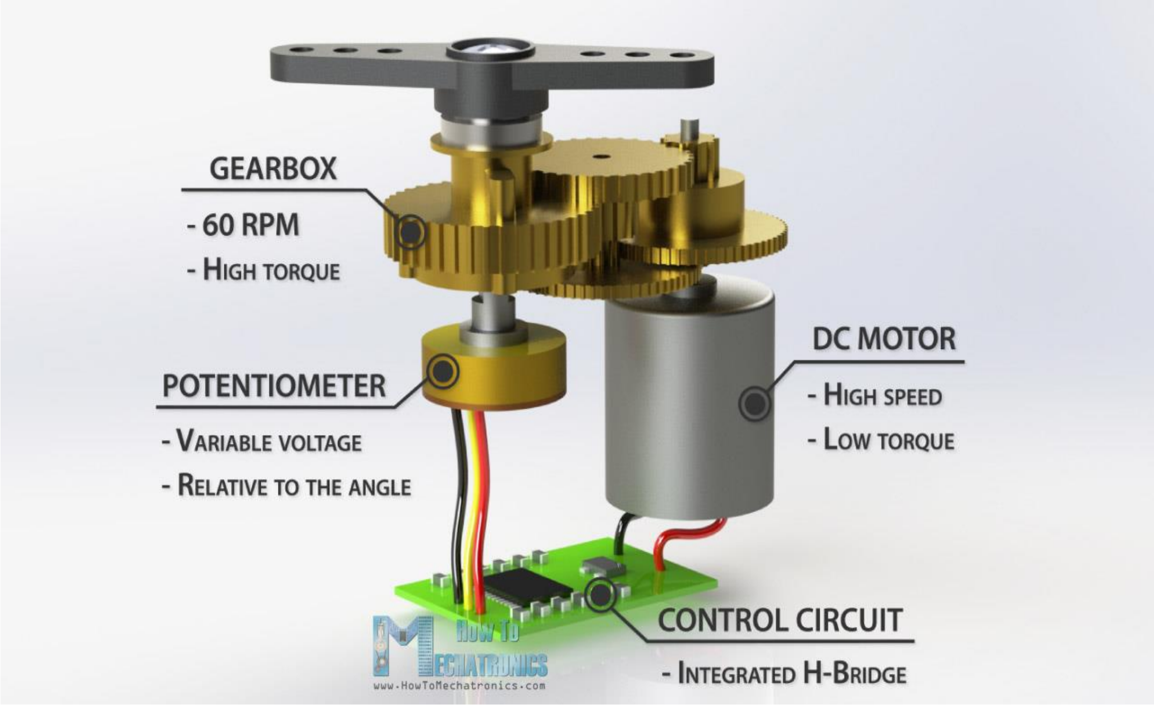
Stepper motors have several advantages:

- Their control is directly compatible with digital technology
- They can be operated open loop by counting steps, with an accuracy of ± 1 step.
- They can be used as holding devices, since they exhibit a high holding torque when the rotor is stationary

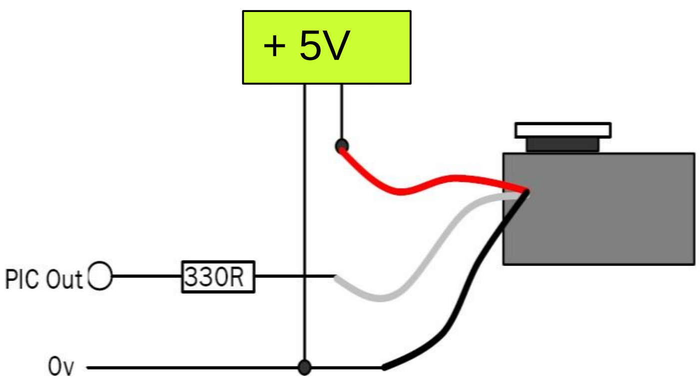
Servo Motor

Servo motor works on the PWM (Pulse Width Modulation) principle, which means its angle of rotation is controlled by the duration of pulse applied to its control PIN. Basically **servo motor** is made up of DC **motor** which is controlled by a variable resistor (potentiometer) and some gears





Servo Motor Detail



Actuator

Reduction
gear

Position feedback

Potentiometer

Small electric DC
motor