Tishk International University
Mechatronics Engineering Department
MEDICAL MECHATRONICS
Lecture 6: 28/11 /2021

Actuators in Medical Applications

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Previous Lecture

- **Sensors : (principle – types – app.)**
- **Transducer**
- **Classification of sensors**
- **Sensors in medical applications**

Outline

- Introduction to Actuators
- Actuators in Biomechatronics systems
- Classification of Actuators
- Electrical actuators
  - Solenoids
  - Electrical motors
    - DC Motor
    - BLDC motor
    - Servo motor
    - Stepper motor

Objectives

- To understand what is the role of the actuators in biomechanical systems
- To know the classification of types of the actuators
- To learn the working principle for each types of the actuators
- To end up with a value of knowledge to be able to make the right decision about the suitable kind of actuators for a desired purpose.

Introduction

- In the previous section we have looked at some basic aspects of measurement systems. We have also noted the fundamental importance of measurement systems within mechatronic products and processes and how they influence the design of such systems.

- In a similar manner, drives and actuators play a primary role in mechatronic systems and their design and development within the integrative nature of a mechatronic approach, is critical for a successful design process.

- As sensors and transducers produce the input to the mechatronic system, while drives and actuators provide the output of the system, influencing the system itself and its environment as depicted in following figure.

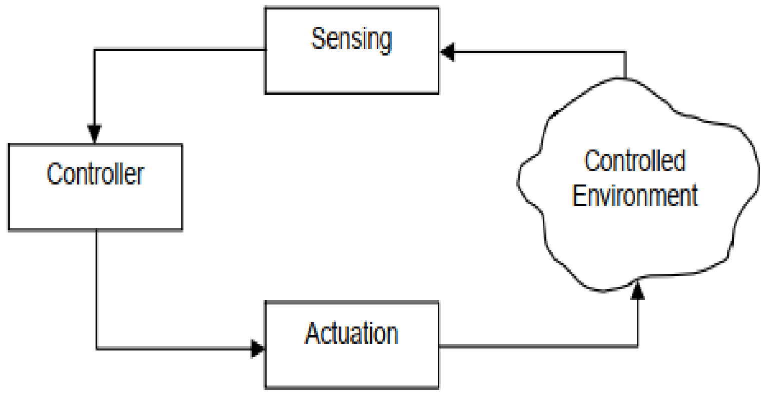


Figure1 : A Mechatronic System illustrating the interaction between controller and environment via sensing and actuation.

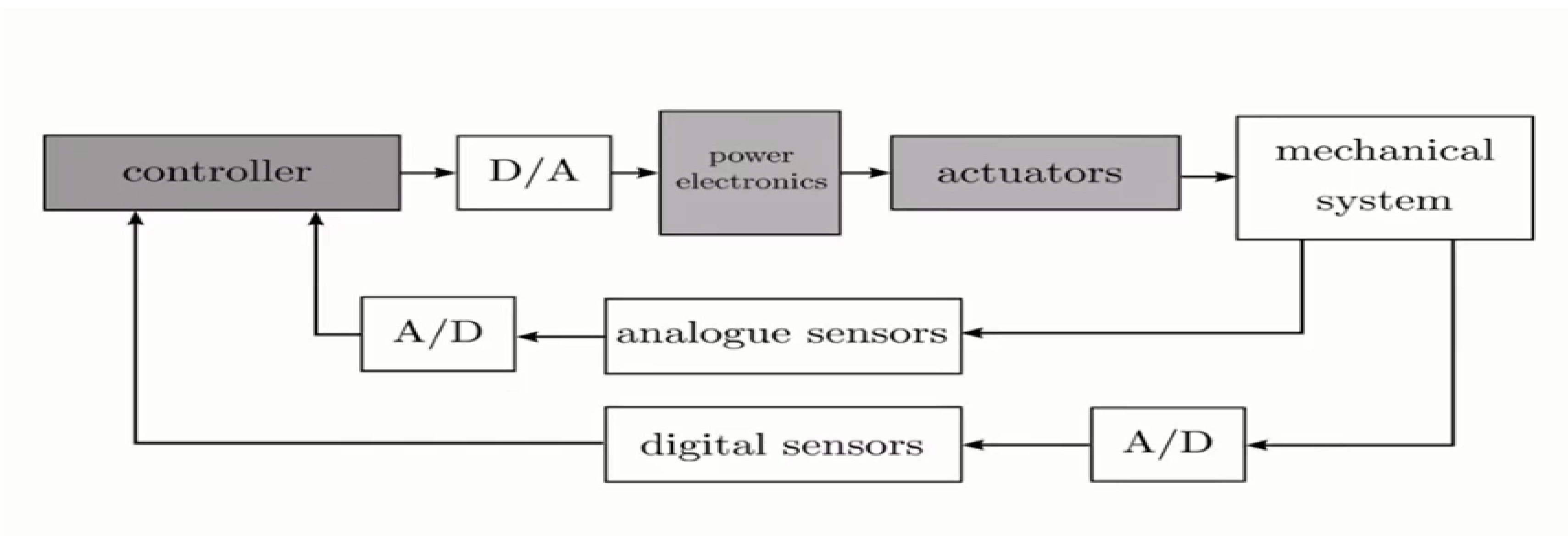


Figure2: Mechatronic Control Loop

Actuators

- *"Actuator is transducer which converts electrical signal into physical quantity".*
- An actuator is a motor that converts **energy** into **torque** which then moves or controls a mechanism or a system into which it has been incorporated.
- Actuator can **introduce motion** as well as **prevent it**.
- The two basic motions of actuators are **linear** and **rotary**.
- An actuator typically runs on **electric** or **pressure** (such as hydraulic or pneumatic), thus actuation system classified in three principal modes of energy transfer, these being the following:

  - Electric power

  - Pneumatics

  - Hydraulics
- The control system can be controlled **mechanically** or **electronically**, **software driven**, or **human operated**.

It is possible to distinguish two components of an actuation system:

1. **The Power Amplification and Modulation Stage**
2. **The Energy Conversion Stage**

These elements of an actuation system are shown in figure 3 (a) while figure 3 (b) represents typical electrohydraulic and electrical actuation systems depicting these two components of an actuation system.

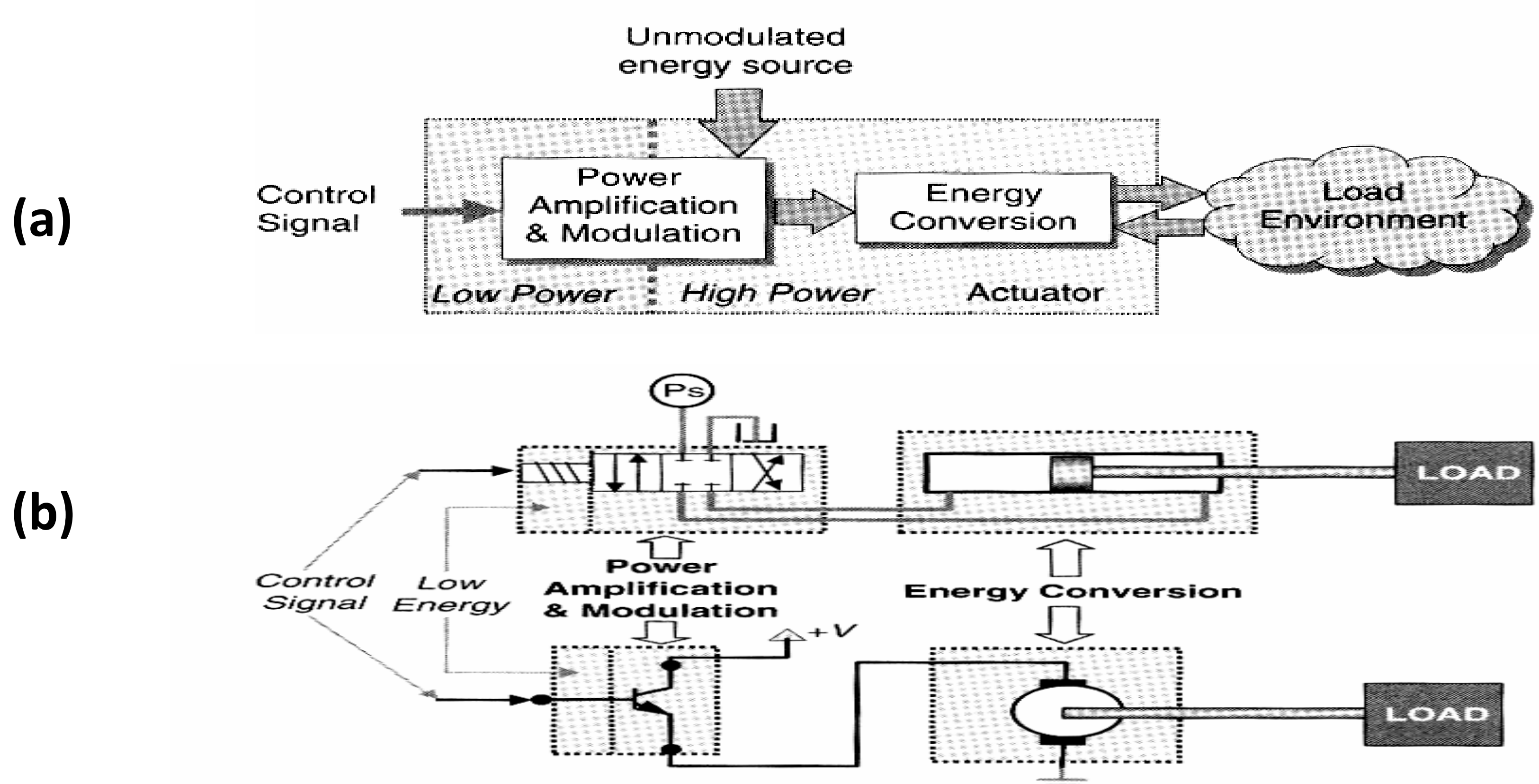


Figure 3: (a) Actuation System functional diagram, (b) Typical electrohydraulic and electrical actuators.

Actuators in Biomechanical Systems

- Most biomechanical systems involve some sort of motion or an action.
- This can range from the articulation of a large exoskeleton through the mechanical stimulation of the tiny bones in the middle ear.
- For instance the actuator could be an artificial muscle. Its job is to produce force and movement. Depending on whether the device is orthotic or prosthetic the actuator can be a motor that assists or replaces the user's original muscle.

Electrical Actuators

- Electrical actuators are simply electro-mechanical devices which allow movement through the use of an **electricity controlled system of gears.**
- Electrical actuators primarily include **Electrical motors** and **Solenoids**.
- **Electrical actuators** comprise the following :

1. **Drive system:** DC motors, AC motors, Stepper & Servo motors
2. **Switching Device:**

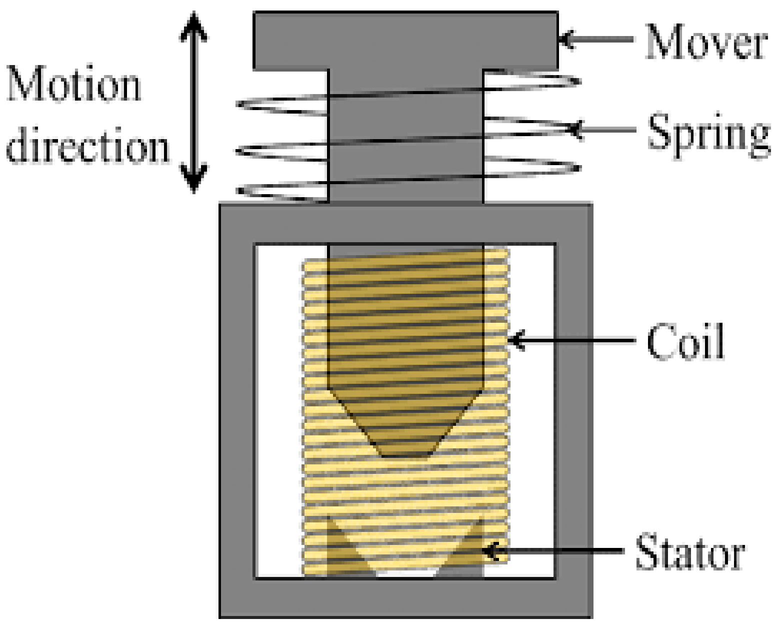
    A - Mechanical switch: Solenoids, Relays

    B - Solid-state switch: Diodes, Thyristor, Transistors

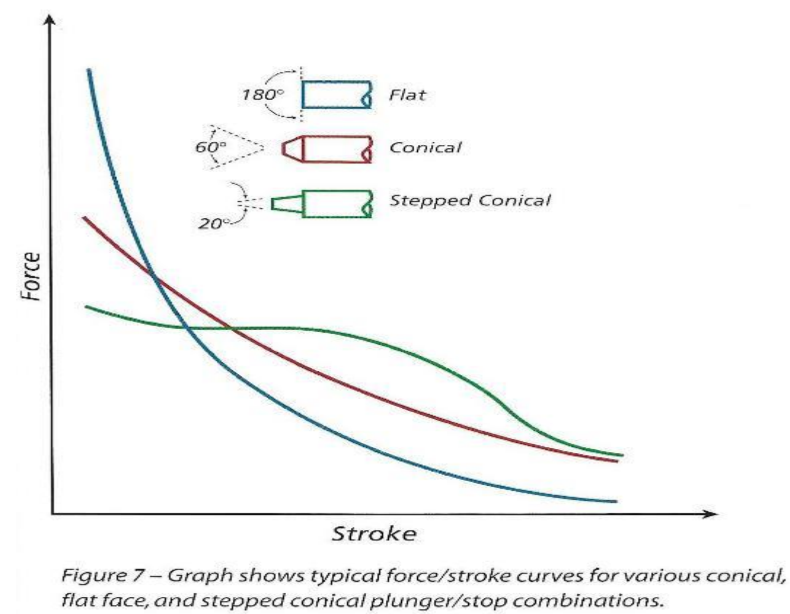
- Electrical motors are frequently used as final controlling element in **position** and **speed** control systems.
- Basically, electrical motors consists of two parts: **Stator** & **Rotor**.

Solenoid as an Actuator

- A solenoid is a device comprised of a coil of wire, the housing and a moveable plunger (armature). When an electrical current is introduced, a magnetic field forms around the coil which draws the plunger in. More simply, a solenoid converts electrical energy into mechanical work.



a)



b)

Figure4: a) the internal structure of the solenoid, b) Relationship between Force and Gap (Stroke)

Animated info: [Solenoid Fundamentals: How Solenoids Work - YouTube]

Solenoid in Medical Applications

- Medical solenoid applications demand high accuracy in terms of force and stroke and stringent standards that ensure *reliability* and *long life*.
- Typical examples include:
  - Dialysis machines
  - Dosing equipment
  - Blood pressure monitoring devices.
- Other applications:
  - locking devices
  - laser operation
  - automotive gearboxes
  - aerospace release mechanisms
  - industrial diverters.

Application - Bone anchored hearing apparatus (BAHA)

- The BAHA consists of a sound processor attached to an external abutment, which is held in place by a titanium screw implanted into the skull behind the ear. The bone carries vibrations that bypass the external and middle ear and travel directly to the cochlear nerve.
- Determine the force on the pin if The diameter of the core is 3mm, the gap is 0.25mm and the peak current through the coil of 500 turns is 2mA.

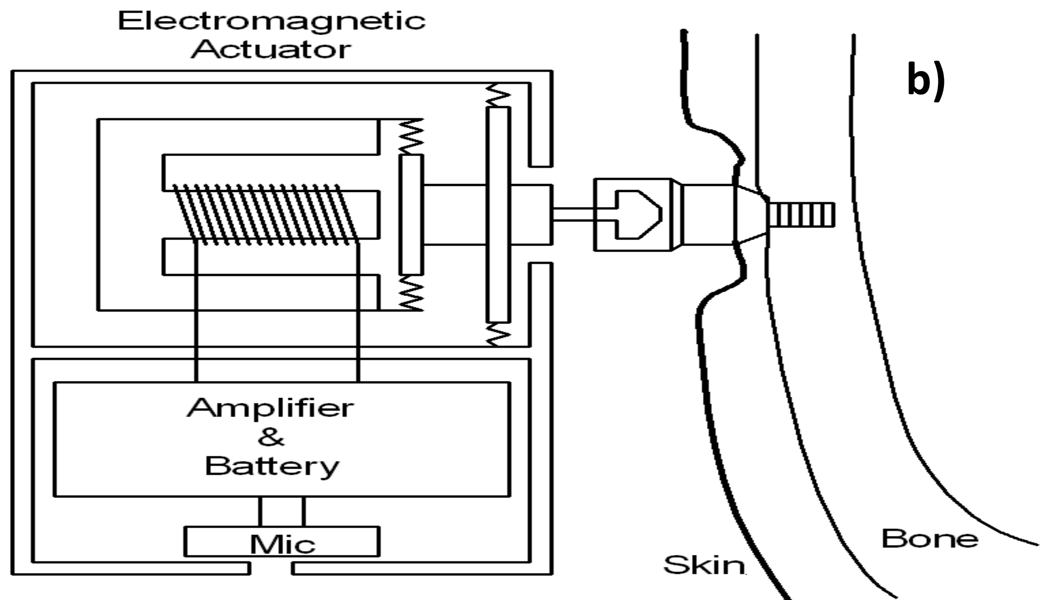
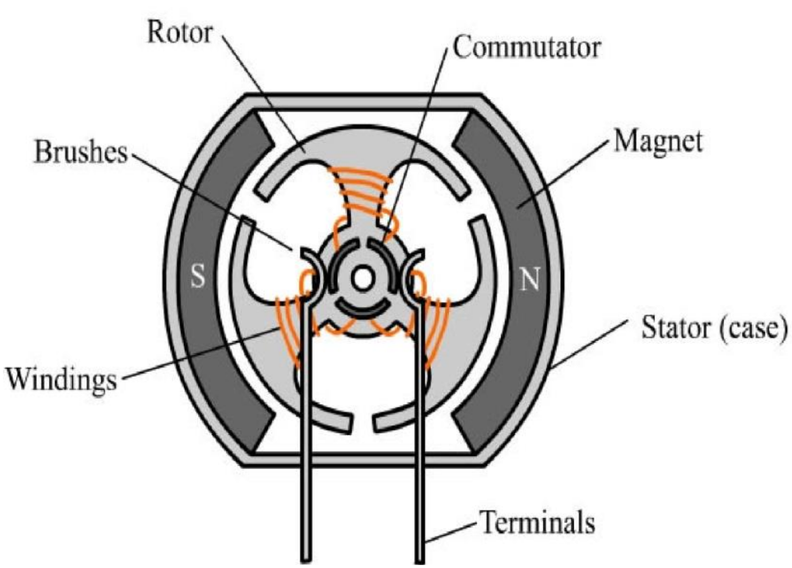


Figure 5: a) Bone anchored hearing apparatus (BAHA) , b) internal structure of BAHA

Animated info: [How the magnetic Baha Attract System works - YouTube]

DC Motors

- DC motors operate through the use of a DC signal.
- DC motors: shaft turns continuously, uses direct current.
- DC motors include two key components: **a stator and an armature**. The stator is the stationary part of a motor, while the armature rotates. In a DC motor, the stator provides a rotating magnetic field that drives the armature to rotate.



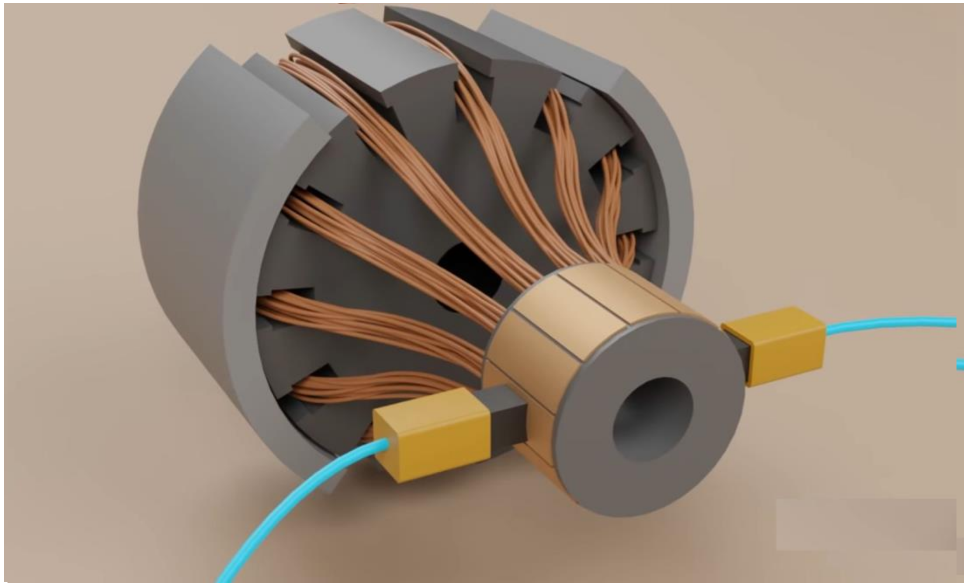


Figure 6: Typical BDC motor in cross section and eternal view of the DC motor.

Gear Boxes

- ***Gear*** is a toothed cylindrical or roller shape component of a machine which meshes with another toothed cylindrical to transmit power from one shaft to another.
- It is mainly used to obtain different torque and speed ratio or changing the direction of driving shaft and driven shaft. **To reduce shaft speeds**, many DC motors are paired with a gearbox. This helps to reduce the motor's shaft speed, and increase the torque output of the motor, is known as gear reduction.

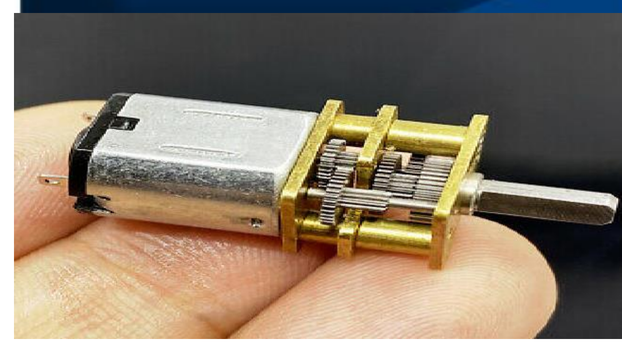


Figure 7: different types of Gear systems and Motor with Gear system

Brushless DC (BLDC) Motors

With the advent of cheap computers and power transistors, it became possible to "turn the motor inside out" and eliminate the brushes. In a brushless DC motor (BLDC), you put the permanent magnets on the rotor and you move the electromagnets to the stator. Then you use a computer (connected to high-power transistors) to charge up the electromagnets as the shaft turns.

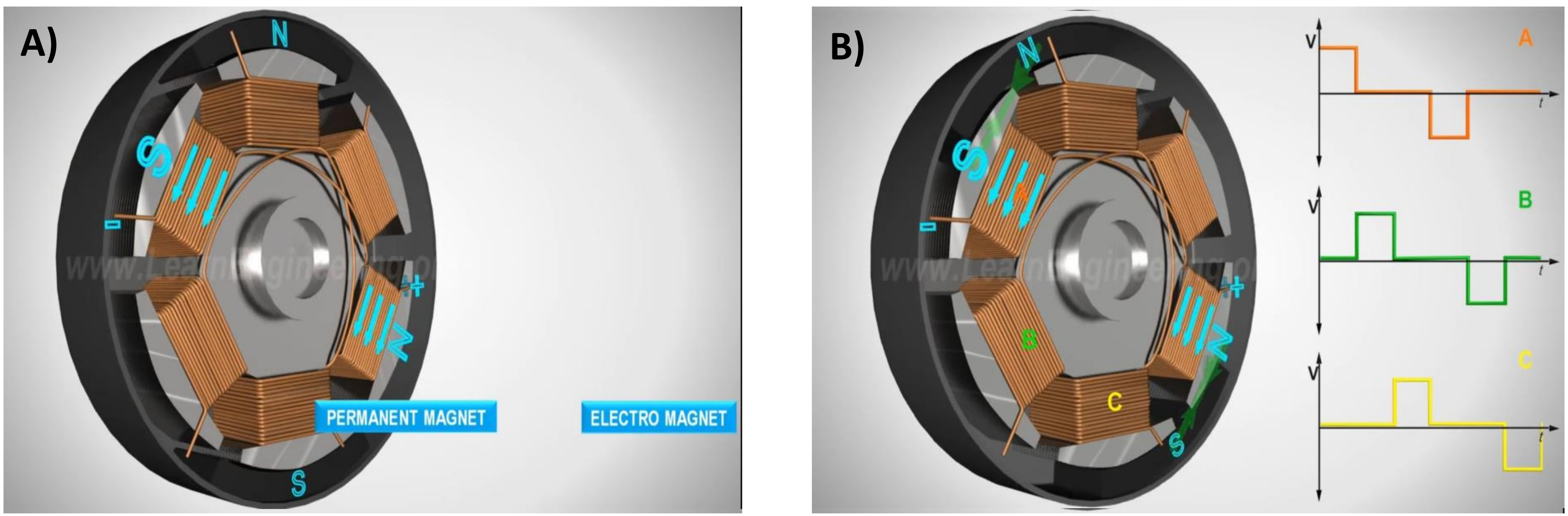
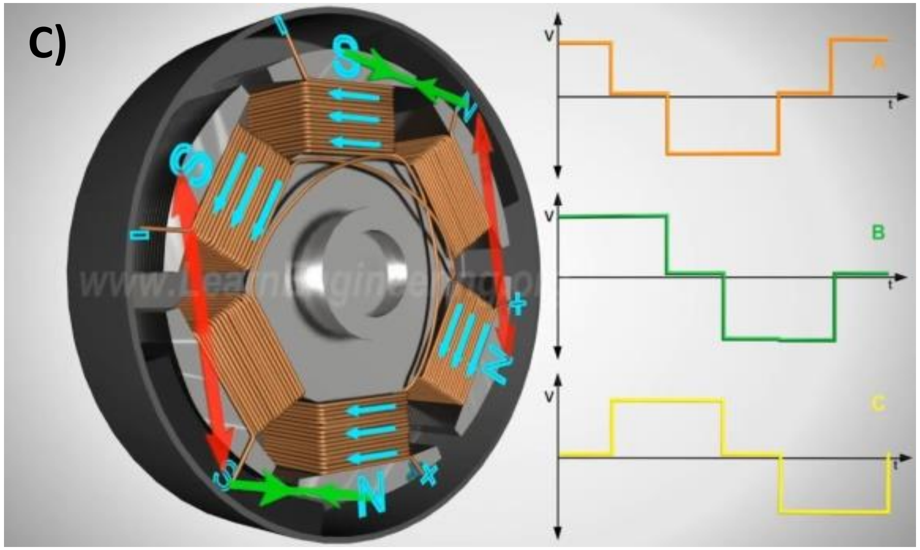
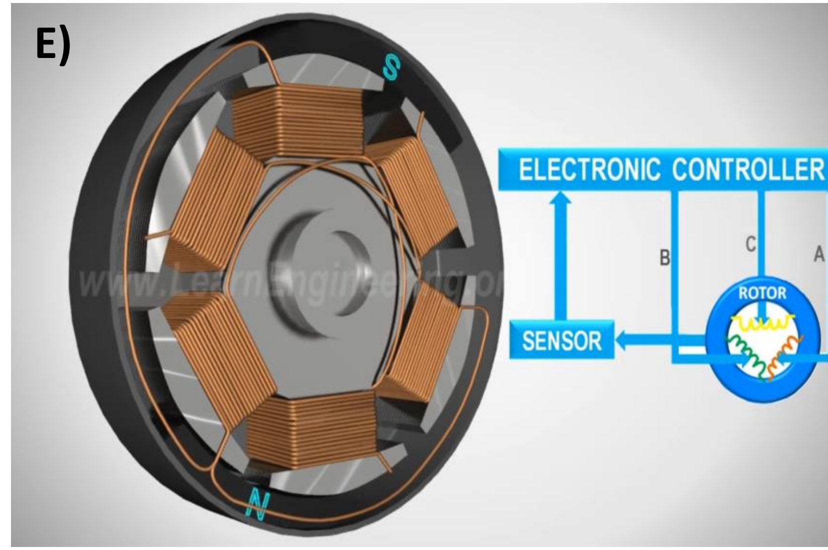
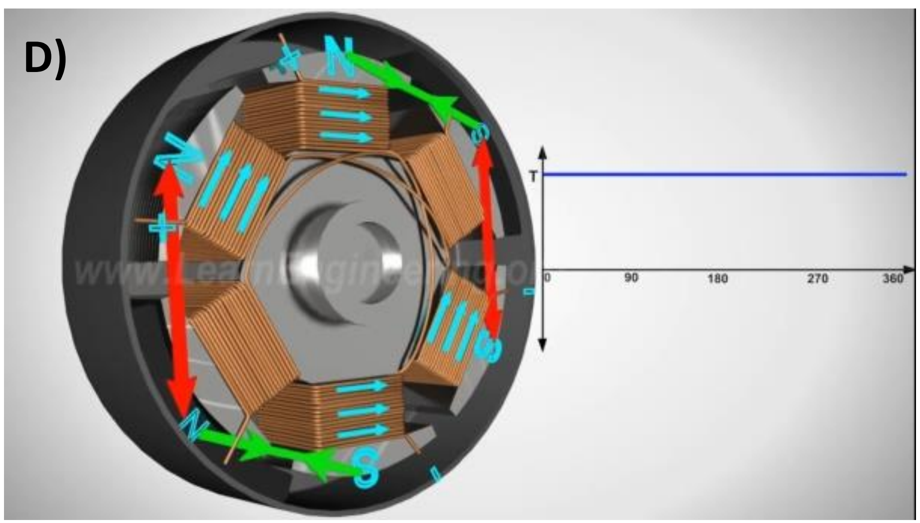


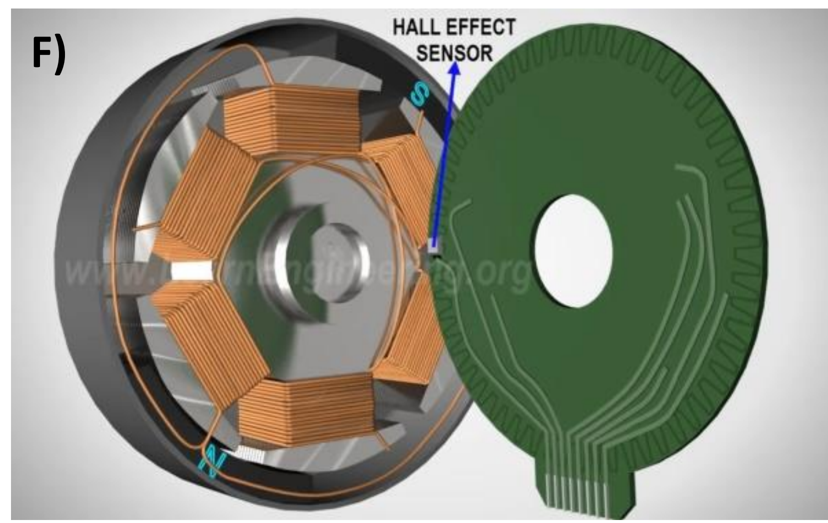
Figure 8: The internal installation of the motor with the electric wave

Brushless DC (BLDC) Motors









Brushless DC (BLDC) Motors

The parameters that govern motor selection for a particular application are as follows:

- Peak torque required for the application
- The range of operating speeds required

Advantages:

- Better speed versus torque characteristics
- High dynamic response
- High efficiency
- Long operating life due to a lack of electrical and friction losses
- Noiseless operation
- Higher speed ranges

Disadvantage:

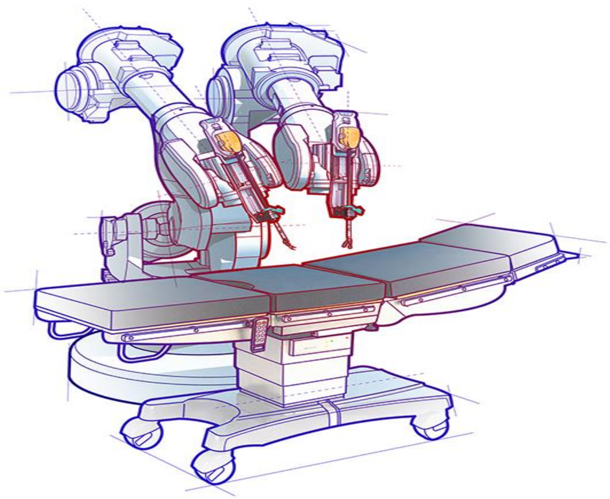
- Its higher initial cost, but can often recover that cost through the greater efficiency over the life of the motor.

BLDC Motors in Medical Applications

- **Reliability of BLDC in Medical applications**: typically require motors to long life. BLDC motors are more reliable than brushed DC motors **because they do not have any brushes to wear out and replace**. The life expectancy of BLDC motors in over 10,000 hours, whereas brushed DC motors have life expectancies of 2,000 to 5,000 hours.
- **BLCD in robotic medical aids**:The overall advantages seen in robotic medical aids that use microdrives over the last few decades, such as motor-powered hand and leg prosthetics, demonstrates that custom BLDC motors can meet strict medical requirements.
- **Selecting miniature motors for surgical devices**: Beyond reliability requirements, surgical device designers must also ensure their end products satisfy exact speed and torque requirements, ability to withstand the high temperatures of sterilization, remain cool during operation, and meet extreme positioning demands.

Hand-tools Surgical Robotics

A)



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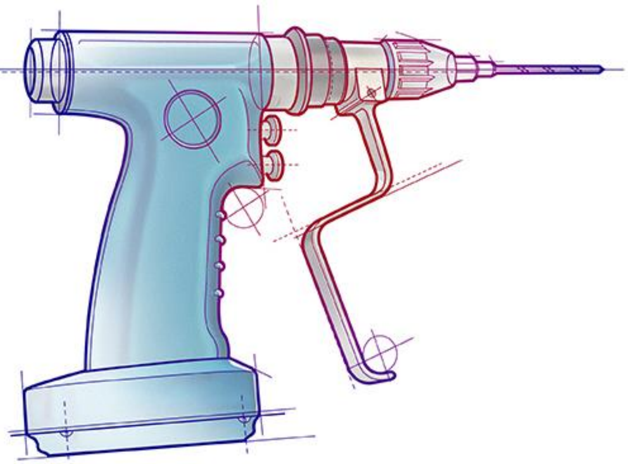

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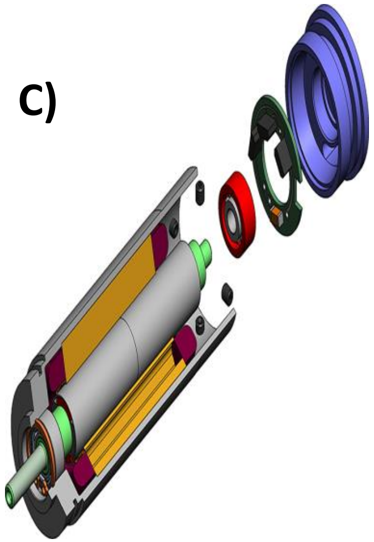


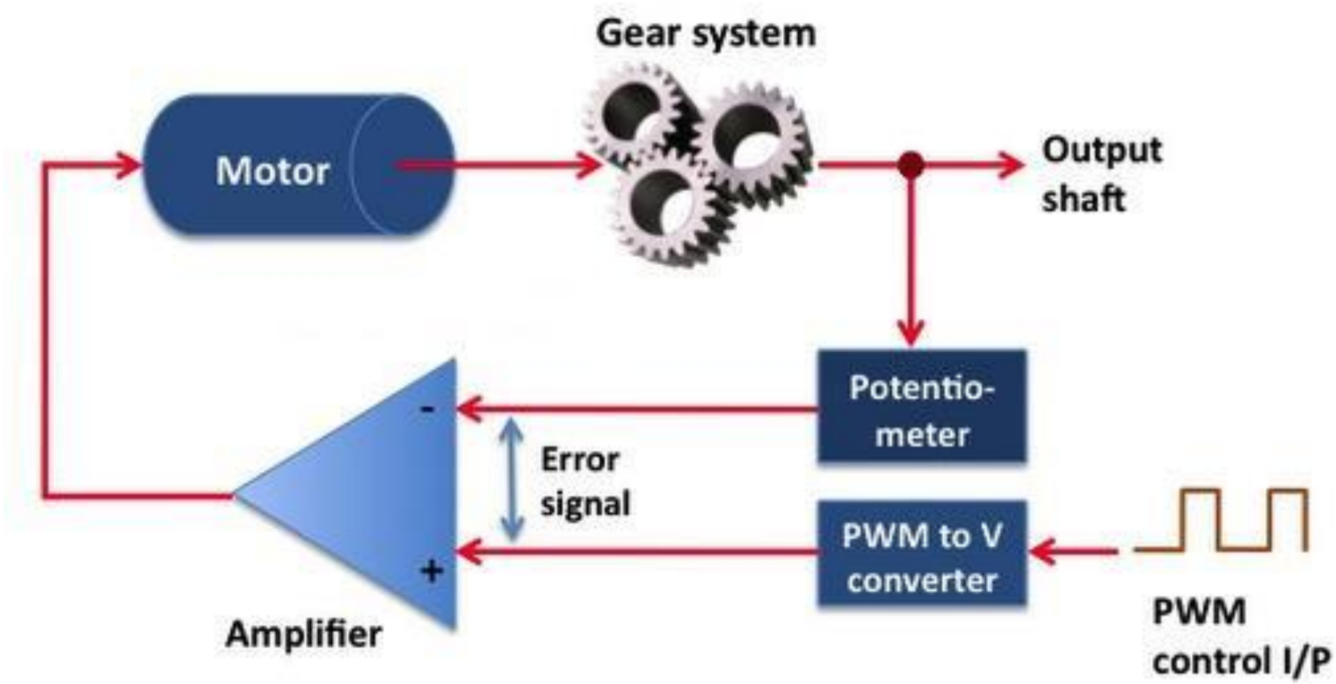
A- Shown here is an example of a surgical robot. **Portescap** tailors motors to such designs with customized *shaft cannulation, motor electromagnetics, mounting features, gear ratios, and pin connections* (instead of flying leads). In short, Portescap's expert design engineers collaborate with device engineers to customize these and other features to the unique requirements surgical handtools or surgical robotics.

B- Shown here is an example of a *powered surgical handtool* so essential in operating rooms. **Portescap** has supplied highly specialized motors for these designs as well as arthroscopic shavers, sagittal and oscillating saws, medium and high-speed drills, other orthopedic drills, wire drivers, and surgical staplers.

C- This is a Portescap Size 9 brushless dc slotted motor.

Servo Motors

- Servo Motor, is a device using (servomechanism) error-sensing feedback to control the performance of a mechanism.
- Servo motor works on PWM (Pulse width modulation) principle, means its angle of rotation is controlled by the duration of applied pulse 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 Configuration

- Servo motor consist 3 wire control:

  Red: DC power (4.8 – 6V)

  Black: Ground

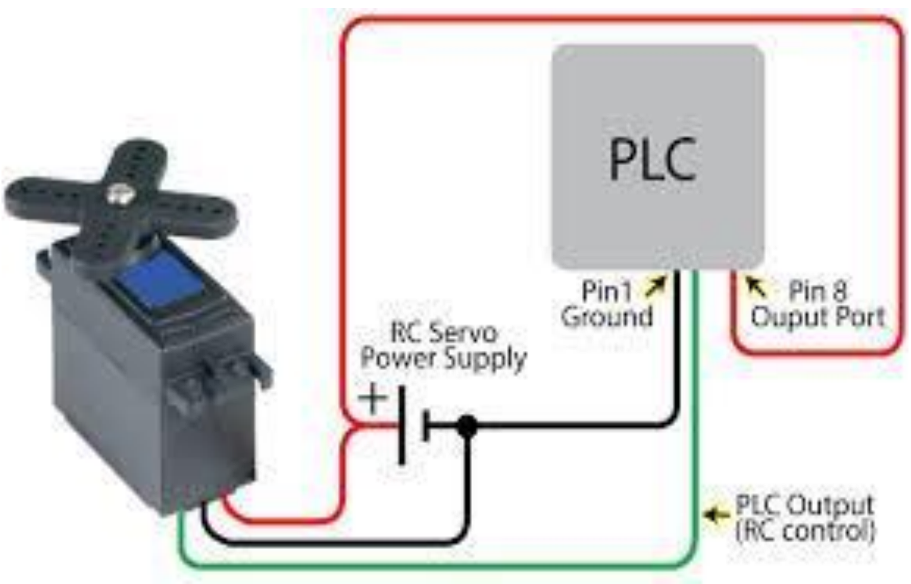
  Green: Position control

- The servo is provided with a pulse every 20ms (or less) with a width that varies from 1.25ms to 1.75ms.

  1.25ms – 0 degree

  1.5ms – 90 degree

  1.75ms – 180 degree



Servo Motors in Medical Industry

- <u>Servo Motor Specifications:</u>

Due to their low cost, good reliability, and the ease with which they can be precisely controlled by microprocessors, different torques are provided by different RC servos, depending on their application.

They are determined by the motor size and its torque as well as the gear ratio of the gearbox .

- <u>Advanced Motion Controls servo drives can be found in lots of common medical applications you may be unaware of including:</u>

Patient handling tables

Patient breathing ventilation

Portable artificial hearts

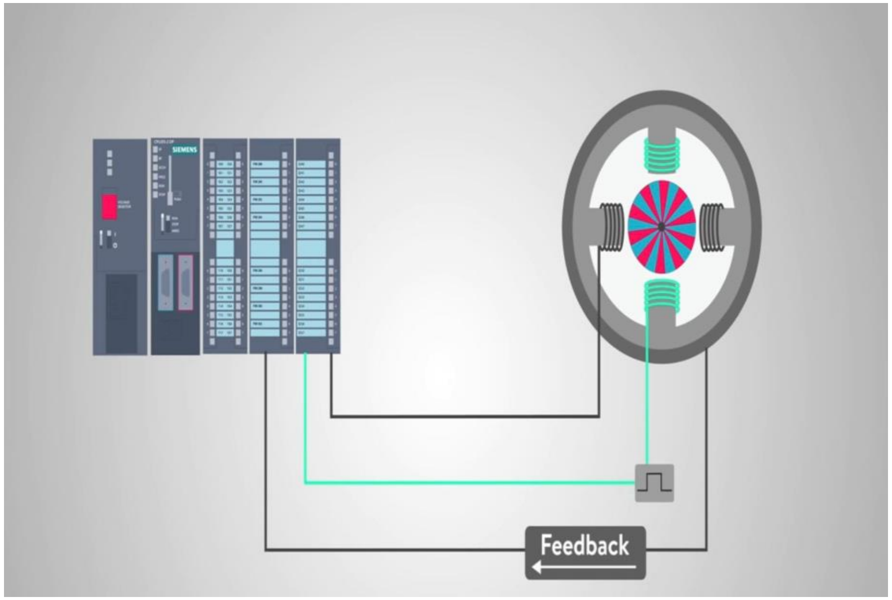
Bone saws (surgical bone cutting machine)➞

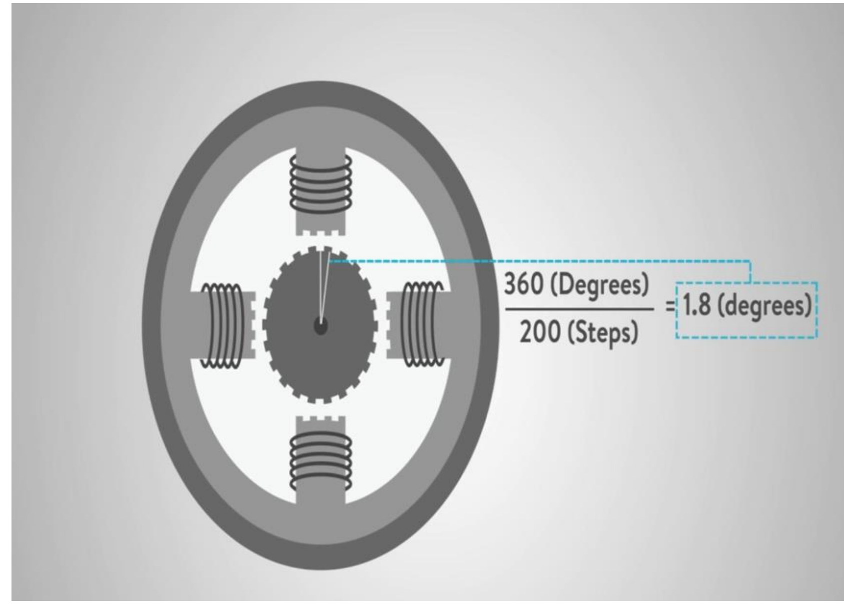
Contras injection … etc

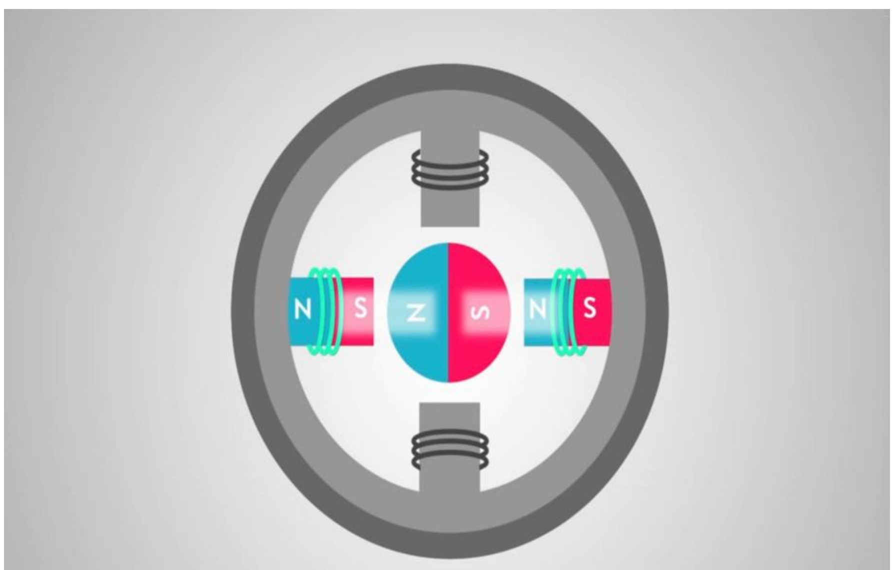
Stepper Motor

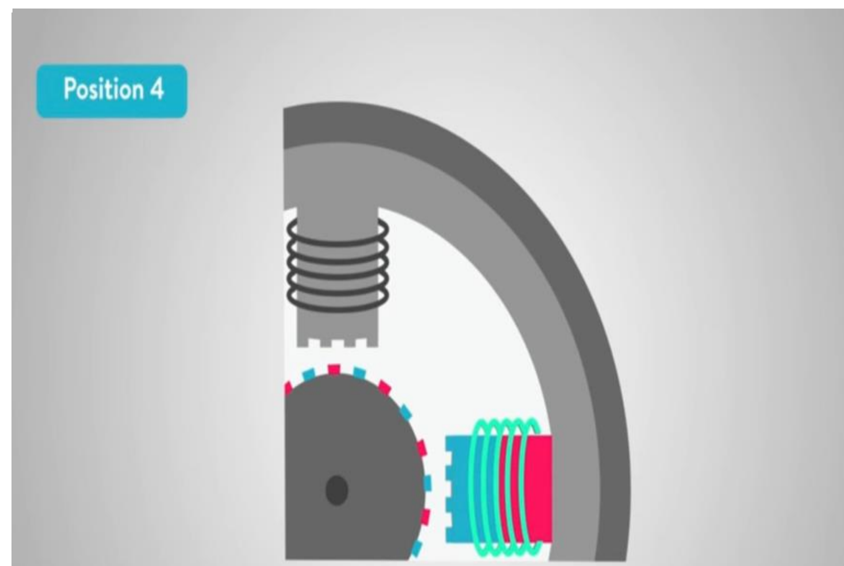
- Stepper motor is a brushless electromechanical motor, the motor have a stationary part (the stator) and a moving part (the rotor). On the *stator*, there are teeth on which coils are wired, while the *rotor* is either a **permanent magnet** or a **variable reluctance** iron core or Hybrid.
- Its main feature that the shaft is rotating by performing a steps. It convert the electric pulses applied at their excitation windings into precisely defined **step-by-step** mechanical shaft rotation.
- The motor internal structure gave the ability to know the exact angular position of the shaft by counting the steps with no need for sensor.
- The **motion control positioning system** with an open loop controller makes the stepper motor fits for a wide range of application.
- Driven by digitally controlled pulses correctly phased that cause them to step by an incremental angle typically between 1.8◦ and 30◦ per step .

Stepper Motor Construction









Stepper Motor in Medical Application

The compact size, precision, efficiency, and quiet operation are critical in the medical field, stepper motors are suitable to be used for :

1. Prosthetics
2. Medical imaging: X-ray, CT, MRI
3. Air pumps ventilators
4. Medical fluid plumps
5. Surgical robots
6. Hospital beds and patient transport