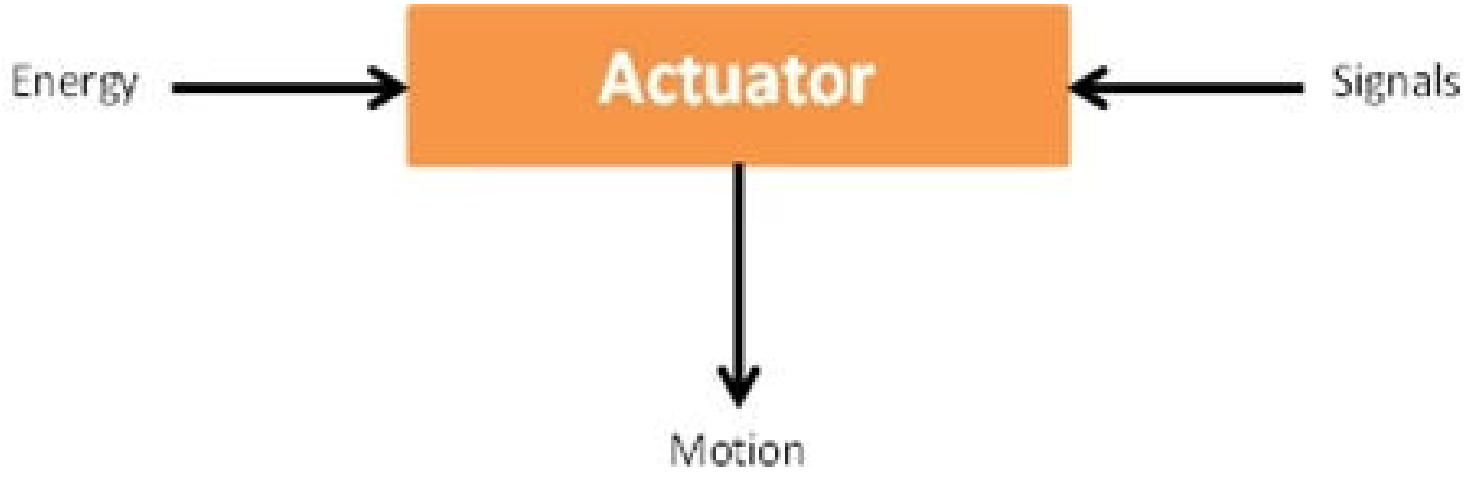
Actuation Systems

Basics of pneumatic and hydraulic systems, mechanical actuation systems, electrical actuation systems, servos.

Actuator

- An **actuator** is a component of a machine that is responsible for moving and controlling a mechanism or system, for example by opening a valve.
- An actuator requires a control device and a source of energy.
- When receives a control signal, an actuator responds by converting the source's energy into mechanical motion.
- Control device is typically valve.



Hydraulic Actuator

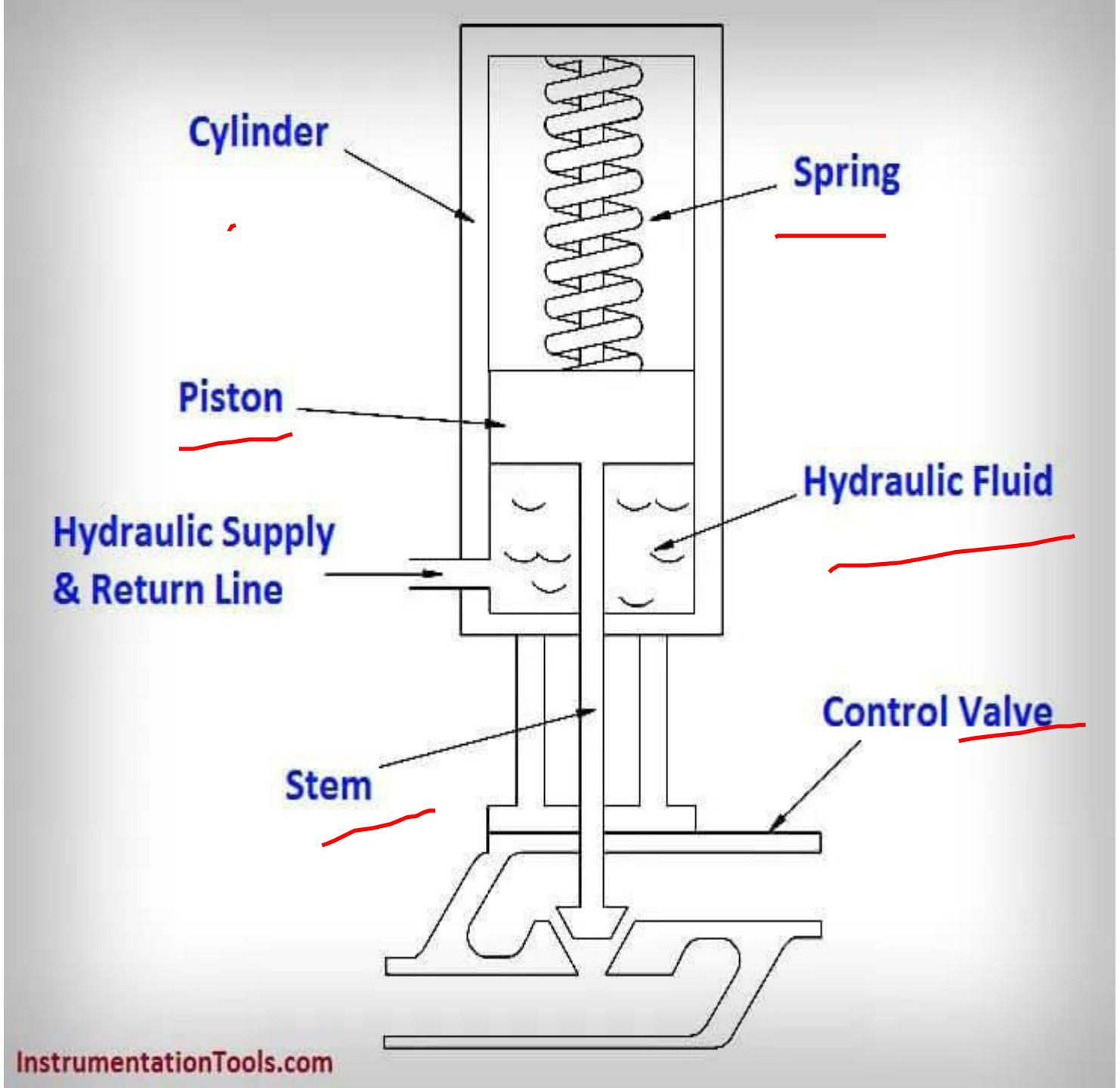
- Hydraulic actuator is a device that is used to change the fluid's pressure energy into mechanical energy.
- The hydraulic actuator includes a cylinder or a fluid motor that works through hydraulic power for mechanical operation.
- The mechanical motion provides an output in the form of rotary, linear otherwise oscillatory motion.
- When liquids are almost unfeasible to compress, then a hydraulic actuator uses a large force.
- When a large amount of force is required to operate a valve, hydraulic actuators are normally used.

Hydraulic Actuator working principle

- it uses liquid pressure to provide a force on the diaphragm to move the valve actuator, then to the stem of the position valve.
- Almost all types of hydraulic actuators use a piston instead of a diaphragm for changing liquid pressure into mechanical power.

- Although hydraulic actuators come in many designs, piston types are most common.
- It consists of a cylinder, piston, spring, hydraulic supply and return line, and stem.
- Piston slides vertically inside the cylinder and separates cylinder into two chambers.
- The upper chamber contains the spring and lower chamber contains hydraulic oil.
- The hydraulic supply and return line is connected to the lower chamber and allows hydraulic fluid to flow to and from the lower chamber of the actuator.
- The stem transmits the motion of the piston to a valve.
- Initially, with no hydraulic fluid pressure, the spring force holds the valve in the closed position.
- As fluid enters the lower chamber, pressure in the chamber increases.

Hydraulic Actuator



- This pressure results in a force on the bottom of the piston opposite to the force caused by the spring.
- When the hydraulic force is greater than the spring force, the piston begins to move upward, the spring compresses, and the valve begins to open.
- As the hydraulic pressure increases, the valve continues to open.
- Conversely, as hydraulic oil is drained from the cylinder, the hydraulic force becomes less than the spring force, the piston moves downward, and the valve closes.
- By regulating amount of oil supplied or drained from the actuator, the valve can be positioned between fully open and fully closed.
- The principles of operation of a hydraulic actuator are to each uses some motive force to overcome spring force to move the valve.

Advantages of Hydraulic Actuators

- Design is simple and construction is strong
- Inexpensive
- They also operate up to 4,000 psi (pounds per square inch).
- Hydraulic actuators are rugged and suited for high force applications.
- They can produce forces 25 times greater than pneumatic cylinders of equal size.
- A hydraulic actuator can hold force and torque stable.
- Hydraulic actuators can have their pumps and motors located a considerable distance away with minimal loss of power.

Disadvantages of a hydraulic actuator :

- Inflexibility
- Sensitive to temperature
- Partial motion control capabilities
- Considerable maintenance requirements
- Its efficiency is low as compared to others
- They need several complementary parts like a liquid reservoir, pump, motor, heat exchangers, and release valves through noise decrease equipment.
- Hydraulics will leak fluid. Loss of liquid can lead to less efficiency and hygiene problems resulting in potential damage to surrounding components and areas.

Applications of a hydraulic actuator

- Various applications like crane drives, self-driven cranes, excavators, wheel motors in military vehicles, feeder drives, agitator drives & mixer, roll mills, tires, drilling rigs, high-powered lawn trimmers & trench cutters.
- Hydraulic jack
- Highly precise positioning for heavy loads
- Hydraulic brake
- Controlling of close-loop velocity

Pneumatic Actuators :

- A simplified diagram of a pneumatic actuator is shown in Figure 1.
- It operates by a combination of force created by air and spring force.
- The actuator positions a control valve by transmitting its motion through the stem.
- A rubber diaphragm separates the actuator housing into two air chambers.
- The upper chamber receives supply air through an opening in the top of the housing.
- The bottom chamber contains a spring that forces the diaphragm against mechanical stops in the upper chamber.
- Finally, a local indicator is connected to stem to indicate the position of the valve.
- The position of the valve is controlled by varying supply air pressure in the upper chamber.
- This results in a varying force on the top of the diaphragm.

Pneumatic Actuators

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Pneumatic means containing or operated by air or gas under pressure

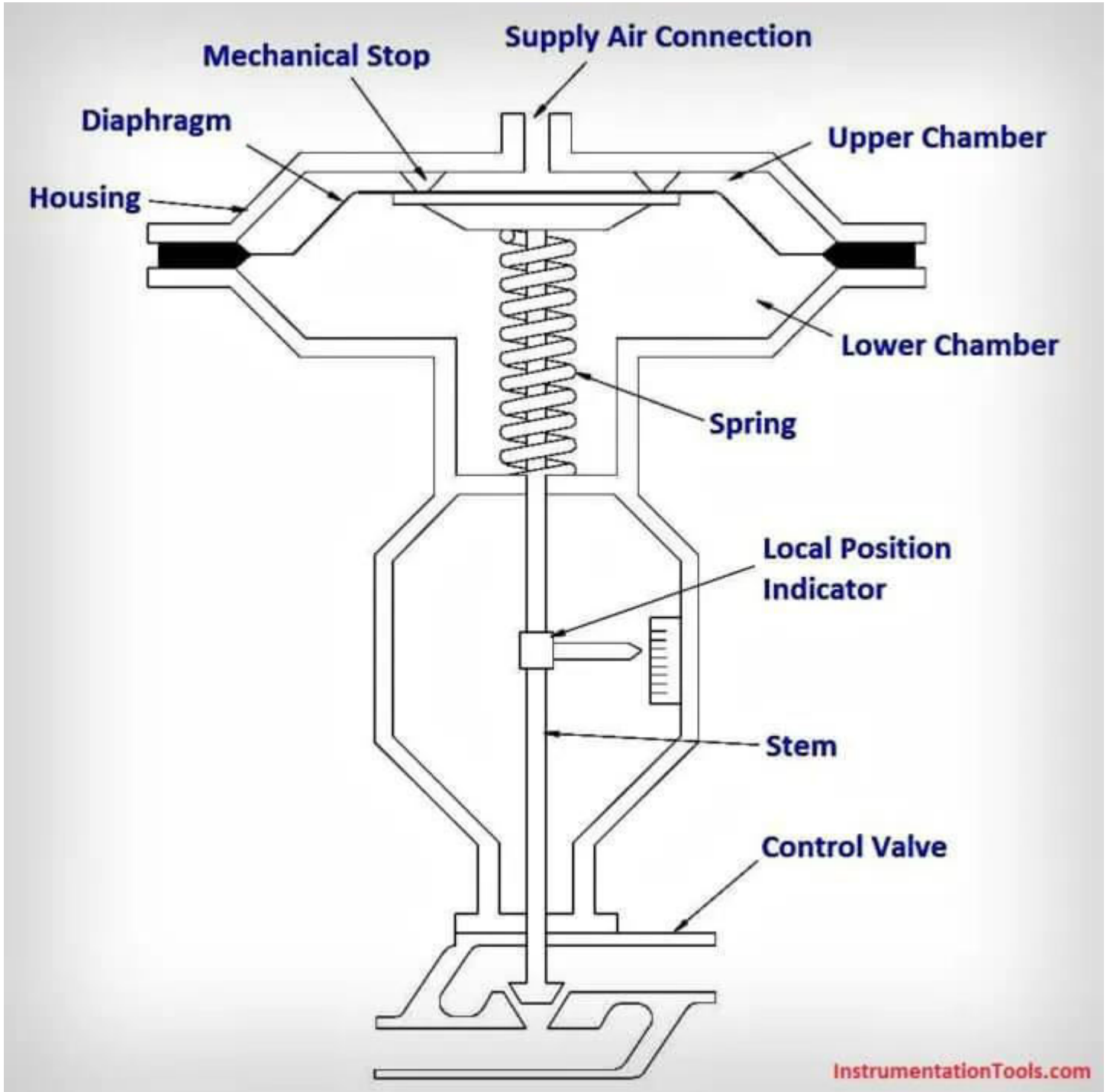
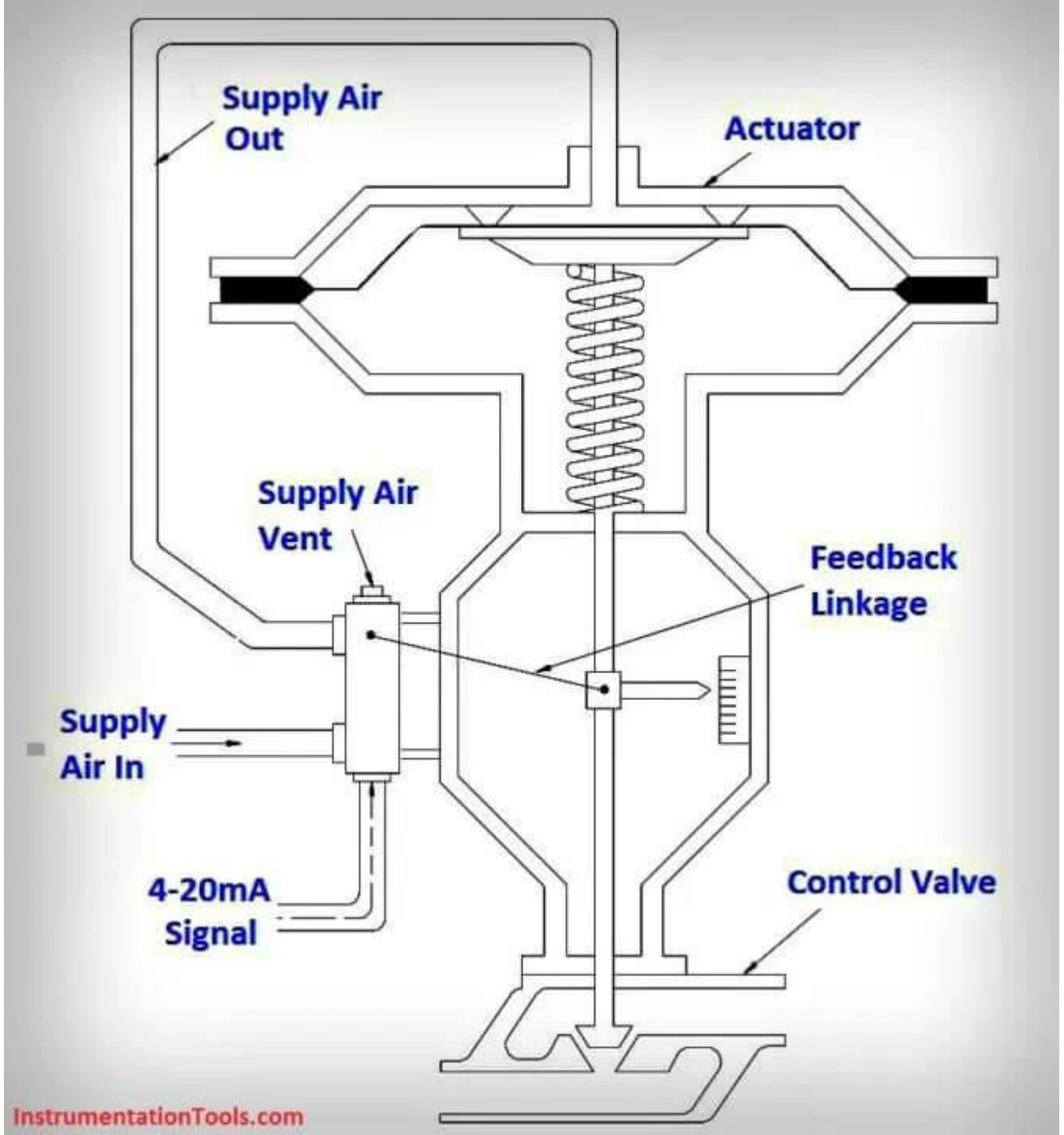


Fig. 1

- Initially, with no supply air, the spring forces the diaphragm upward against the mechanical stops and holds the valve fully open.
- As supply air pressure is increased from zero, its force on top of the diaphragm begins to overcome the opposing force of the spring.
- This causes the diaphragm to move downward and the control valve to close.
- With increasing supply air pressure, the diaphragm will continue to move downward and compress the spring until the control valve is fully closed.
- Conversely, if supply air pressure is decreased, the spring will begin to force the diaphragm upward and open the control valve.
- Additionally, if supply pressure is held constant at some value between zero and maximum, the valve will position at an intermediate position.

- Therefore, the valve can be positioned anywhere between fully open and fully closed in response to changes in supply air pressure
- A **positioner** is a device that regulates supply of air pressure to pneumatic actuator.
- It does this by comparing the actuator's demanded position with the control valve's actual position.
- The demanded position is transmitted by an electrical control signal from a controller to the positioner.
- The pneumatic actuator is shown (Fig 2) with a controller and positioner added.
- The controller generates an output signal that represents the demanded position.
- This signal is sent to the positioner, which responds by increasing or decreasing the supply air to the actuator.

Pneumatic Actuators



Advantages of Pneumatic Actuators

- Pneumatic actuators' can work in extreme temperatures, a typical temperature range is -40°F to 250°F.
- In terms of safety and inspection, using air and pneumatic actuators avoids using hazardous materials.
- They also meet explosion protection and machine safety requirements because they create no magnetic interference due to the lack of motors.
- Pneumatic actuators are lightweight.
- It can store compressed air and use it again efficiently without the risk of fire.
- These are extremely durable and reduce the costs required to maintain.
- Less maintenance means a longer product lifecycle and therefore greater output.

Disadvantages of Pneumatic Actuators

- Pressure losses and compressibility of air make pneumatics less efficient than other methods.
- Operations at lower pressures will have lower forces and slower speeds.
- To be truly efficient, pneumatic actuators must be sized for a specific job. Hence, they cannot be used for other applications.
- Even though air is readily available, it can be contaminated by oil or lubrication, leading to downtime and maintenance.
- Companies still have to pay for compressed air, making it a consumable, along with the compressor and line maintenance costs.

Applications of pneumatic actuators

- Most commonly known for being highly reliable, efficient, and safe sources of motion control, pneumatic actuators are among the most popular engineering devices.
- They also hold value within industrial applications where there is a fire or ignition risk.
- Some of the most common applications include :

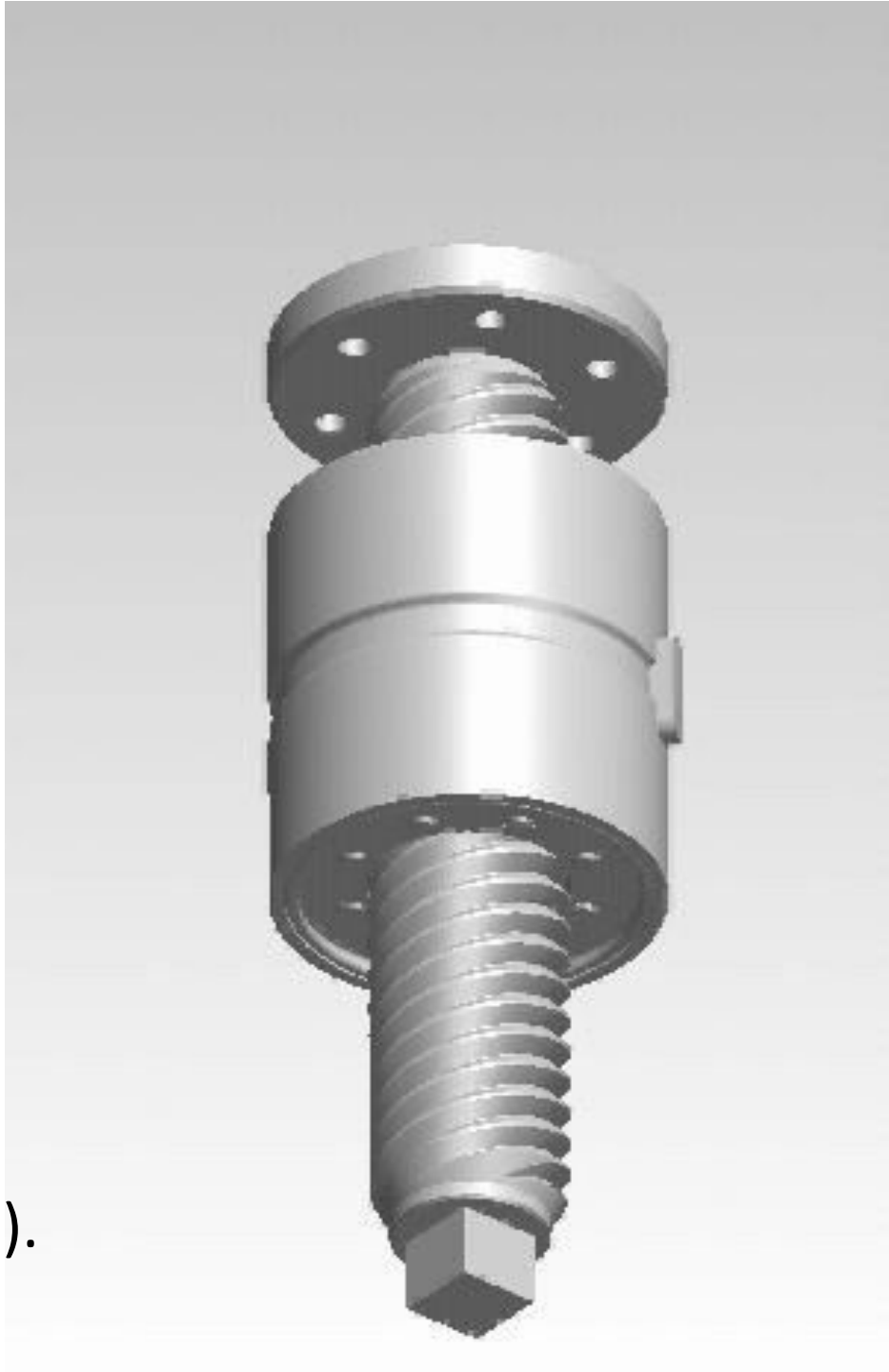
  - ❖ Combustible automobile engines
  - ❖ Air compressors
  - ❖ Packaging & production machinery
  - ❖ Railway application
  - ❖ Aviation.

Mechanical Actuators

- A mechanical actuator functions to execute movement by converting one kind of motion, such as rotary motion, into another kind, such as linear motion.
- The operation of mechanical actuators is based on combinations of structural components, such as screw, or pulleys and chains.
- A Chain Block (hand chain pulley hoist) is a mechanism used to lift and lower heavy loads using a chain.
- Chain blocks contain two wheels in which the chain is wound around.
- When the chain is pulled, it winds around the wheels and begins to lift the item that is attached to the rope or chain via a hook.

Screw:

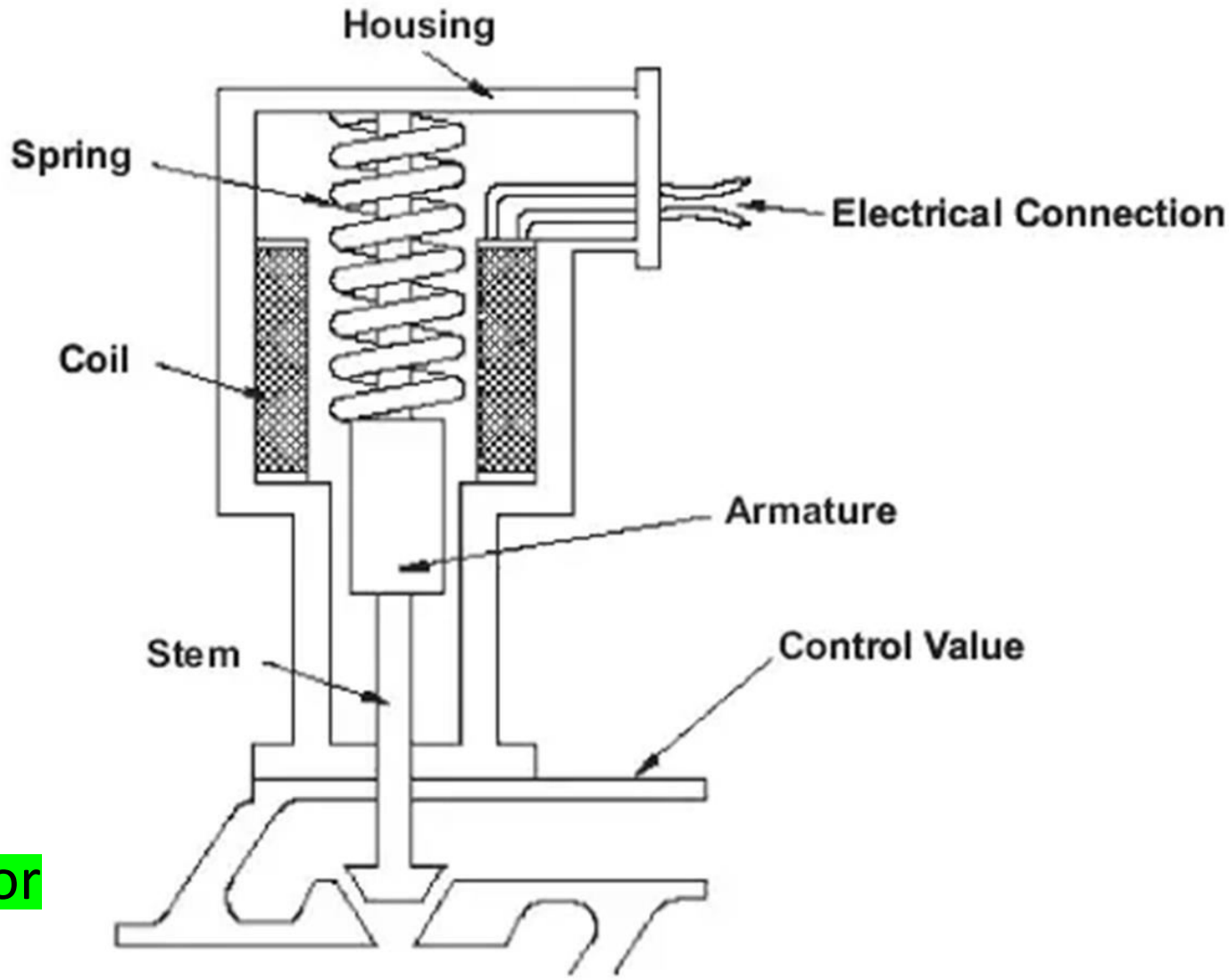
- leadscrew, screw jack, ball screw and roller screw actuators all operate on the principle of the simple machine known as the screw.
- By rotating the actuator's nut, the screw shaft moves in a line.



Roller screw actuation with traveling screw (rotating nut).

Electric Actuators

- Electric actuators are devices that convert electrical energy into a mechanical force or kinetic energy, capable of causing movements in a part of an appliance.
- An electric actuator is powered by an electric motor.



Working principle of an Electric Actuator

Components of Electric Actuators

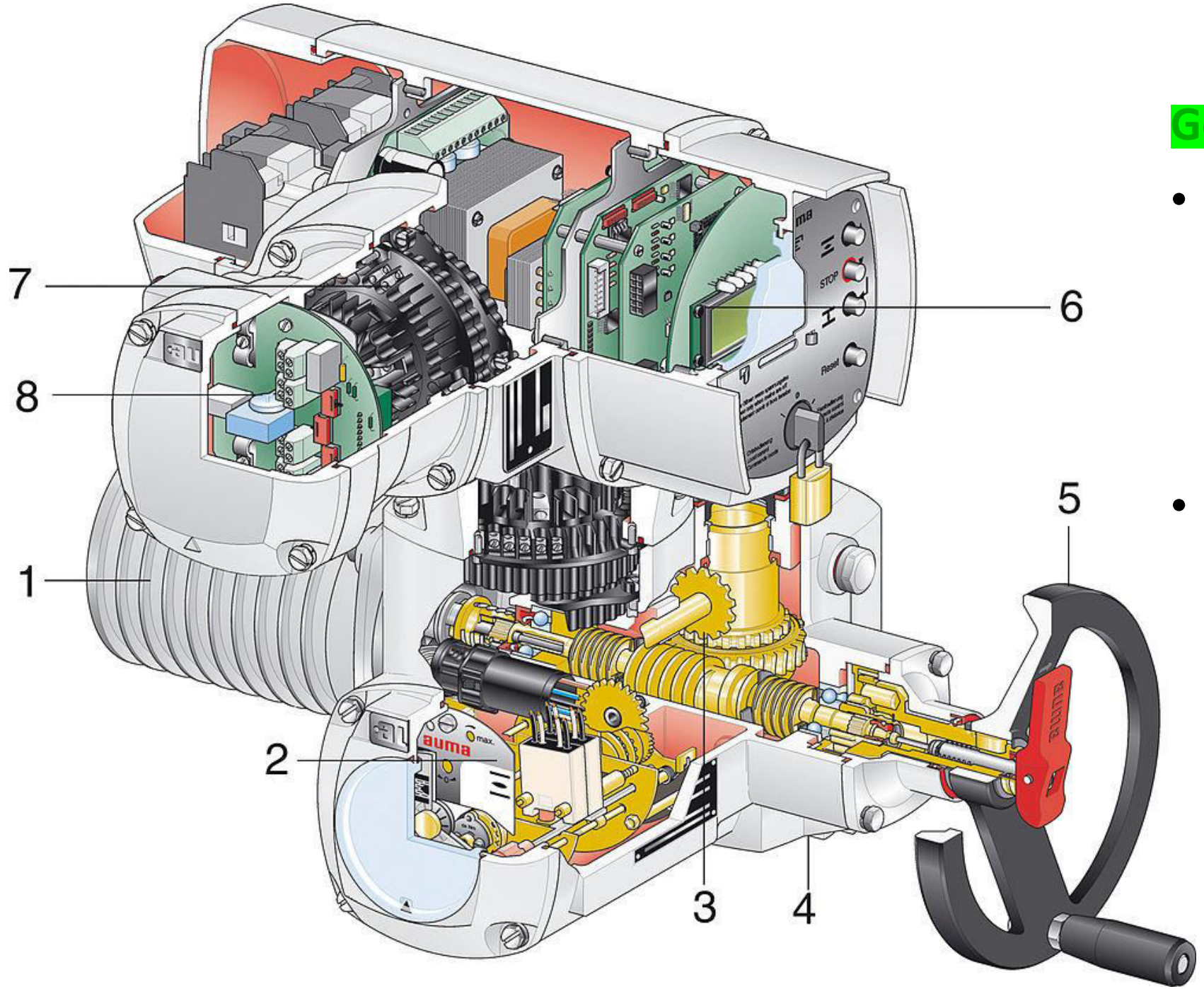
The specific components of an electric actuator may vary depending on the type and application of the actuator, but here are some of the common components found in most electric actuators:

Motor (1)

- Robust asynchronous three-phase AC motors are mostly used as the driving force.
- For some applications also single-phase AC or DC motors are used.

Limit and torque sensors (2)

- The limit switches signal when an end position has been reached.
- The torque switching measures the torque present in the valve.
- When exceeding a set limit, this is signaled in the same way.



Gearing (3)

- Often a worm gearing is used to reduce the high output speed of the electric motor.
- It prevents accidental and undesired changes of the valve position by acting upon the valve's closing element.

Valve attachment (4)

- The valve attachment consists of two elements.
- First: The flange used to firmly connect the actuator to the counterpart on the valve side. The higher the torque to be transmitted, the larger the flange required.
- Second: The output drive type used to transmit the torque or the thrust from the actuator to the valve shaft.

Manual operation (5)

- In their basic version most electric actuators are equipped with a handwheel for operating the actuators during commissioning or power failure.

Actuator controls (6)

- Both actuator signals and operation commands are processed within the actuator controls. This task can in principle be assumed by external controls, e.g. a PLC.
- Modern actuators include integral controls which process signals locally without any delay.

Electrical connection (7)

- The supply cables of the motor and the signal cables for transmitting the commands to the actuator and sending feedback signals on the actuator status are connected to the electrical connection.

Fieldbus connection (8)

- Fieldbus technology is increasingly used for data transmission in process automation applications.

Classification of Electric actuators

Electric actuators can be classified in the following groups:

Electromagnetic actuators:

- It consist of a wire coil wrapped around a magnetic core.
- When an electrical current is passed through the coil, it creates a magnetic field that interacts with the magnetic core, causing it to move.
- The amount and direction of the movement depend on the polarity and strength of the magnetic field, as well as the physical characteristics of the actuator.

Piezoelectric actuators:

- These use a material, such as quartz or ceramic, that generates an electric charge when it is subjected to mechanical stress.
- When a voltage is applied to the material, it causes it to expand or contract, generating mechanical motion.
- The amount and direction of the motion depend on the polarity and magnitude of the applied voltage, as well as the physical characteristics of the actuator.

Electrohydraulic actuator

- In electrohydraulic actuator, electric motor remains the prime mover but provides torque to operate a hydraulic accumulator that is used to transmit actuation force in the same way that diesel engine/hydraulics are typically used in heavy equipment.

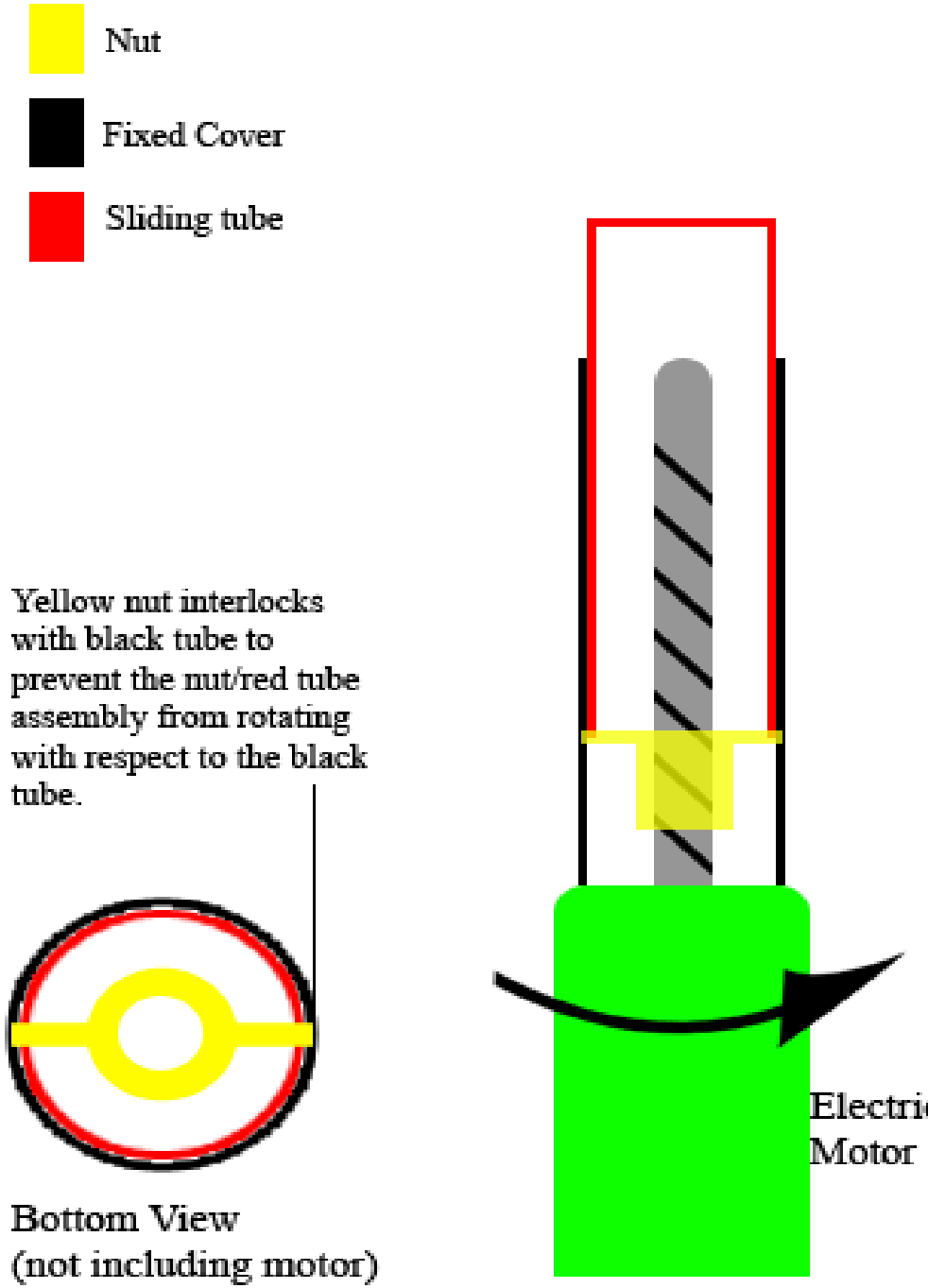
Electromechanical actuator (EMA)

- It converts the rotational force of an electric rotary motor into a linear movement through a mechanism either a belt or a screw.
- The main advantages of electromechanical actuators are:
  - Relatively good level of accuracy respect to pneumatics,
  - Possible long lifecycle
  - The little maintenance effort required (might require grease).
  - It is possible to reach relatively high force, on the order of 100 kN.
- The main application of such actuators is seen in health care devices and factory automation

Linear actuator

- A linear actuator is an actuator that creates motion in a straight line.
- These are used in machine tools and industrial machinery, in computer peripherals such as disk drives, printers, in valves, dampers etc.
- Linear motor technology is the best solution in the context of a low load (up to 30Kgs).

Conceptual design of a basic traveling-nut linear actuator. The lead screw (gray) rotates while the lead nut (yellow) and tube (red) do not.



Applications of Electrical Actuators

- **Industrial automation**: Electrical actuators are used in various industrial machines and processes, such as conveyor systems, packaging machines, assembly lines etc.
- **Aerospace and defense**: EA are used in aircraft and spacecraft, such as landing gear, flaps, and control surfaces, to provide precise and reliable control of motion.
- **Automotive:** EAs are used in various automotive systems, such as power windows, door locks, and seats, to provide comfortable and convenient control of motion.
- **Robotics:** EAs are used in various robotic systems, such as robot arms and grippers, to provide precise and flexible control of motion.
- **Medical devices**: Electric actuators are used in surgical robots and prosthetic limbs, various medical devices to provide precise and reliable motion control.
- **Consumer products:** Such as home appliances, toys, electronics etc.

Advantages of Electrical Actuators

- Very accurate control and positioning
- Able to stop at any point of the stroke
- Easy to set acceleration and deceleration
- No external sensors
- Low operating costs
- Help adapt machines to flexible processes
- Superior performance at high speeds
- Minimal maintenance
- Low risk of contamination

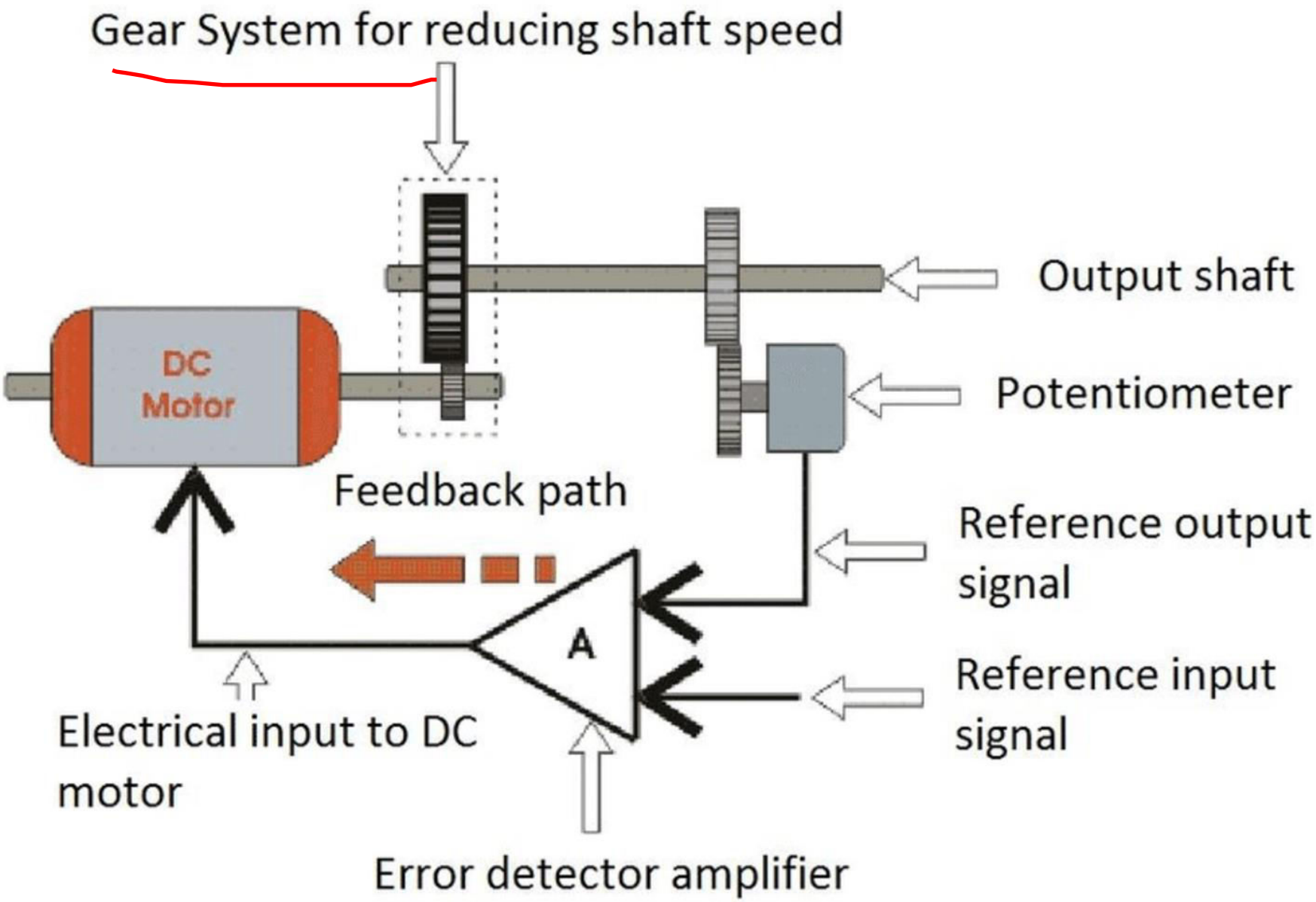
Disadvantages of Electrical Actuators

- One prominent disadvantage can be a higher initial equipment cost.
- Non-explosion proof
- Sensitive to vibration
- More complex technology
- High speeds, less thrust
- High thrust, less speed

Servo Motor

- A servo motor is defined as a linear or rotary type of actuator that provides fast precision position control for closed-loop position control applications.
- As compared to large industrial electric motors, servo motors are not useful for continuous energy conversion.
- These motors have a high-speed response due to how inertia and are designed with small diameters and long rotor lengths.
- Servo motors have a mechanism that uses position feedback to control the speed and final position of the motor.
- These types of motors are best suited for smaller applications.

Working Principle of Servo Motor



Working Principle of Servo Motor

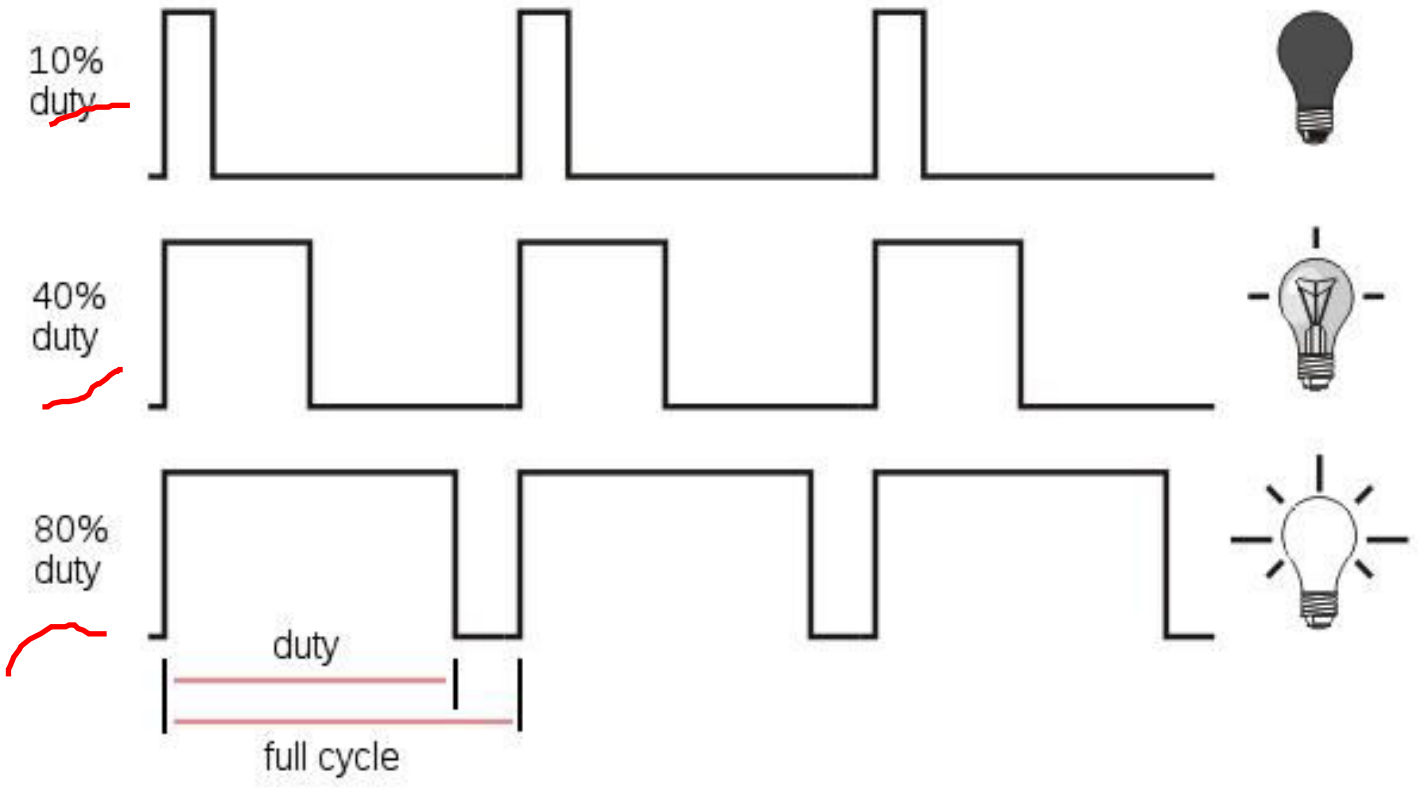
- A servo consists of a Motor (DC or AC), a potentiometer, gear assembly, and a controlling circuit.
- Gear assembly is used to reduce RPM and to increase torque of the motor.
- At initial position of servo motor shaft, the position of the potentiometer knob is such that there is no electrical signal generated at the output port of the potentiometer.
- Now an electrical signal is given to another input terminal of the error detector amplifier.
- Now the difference between these two signals, one comes from the potentiometer and another comes from other sources, will be processed in a feedback mechanism and output will be provided in terms of error signal.

Working Principle of Servo Motor

- This error signal acts as the input for motor and motor starts rotating.
- Now motor shaft is connected with the potentiometer and as the motor rotates so the potentiometer and it will generate a signal.
- So as the potentiometer's angular position changes, its output feedback signal changes.
- After sometime the position of potentiometer reaches at a position that the output of potentiometer is same as external signal provided.
- At this condition, there will be no output signal from the amplifier to the motor input as there is no difference between external applied signal and the signal generated at potentiometer, and in this situation motor stops rotating.

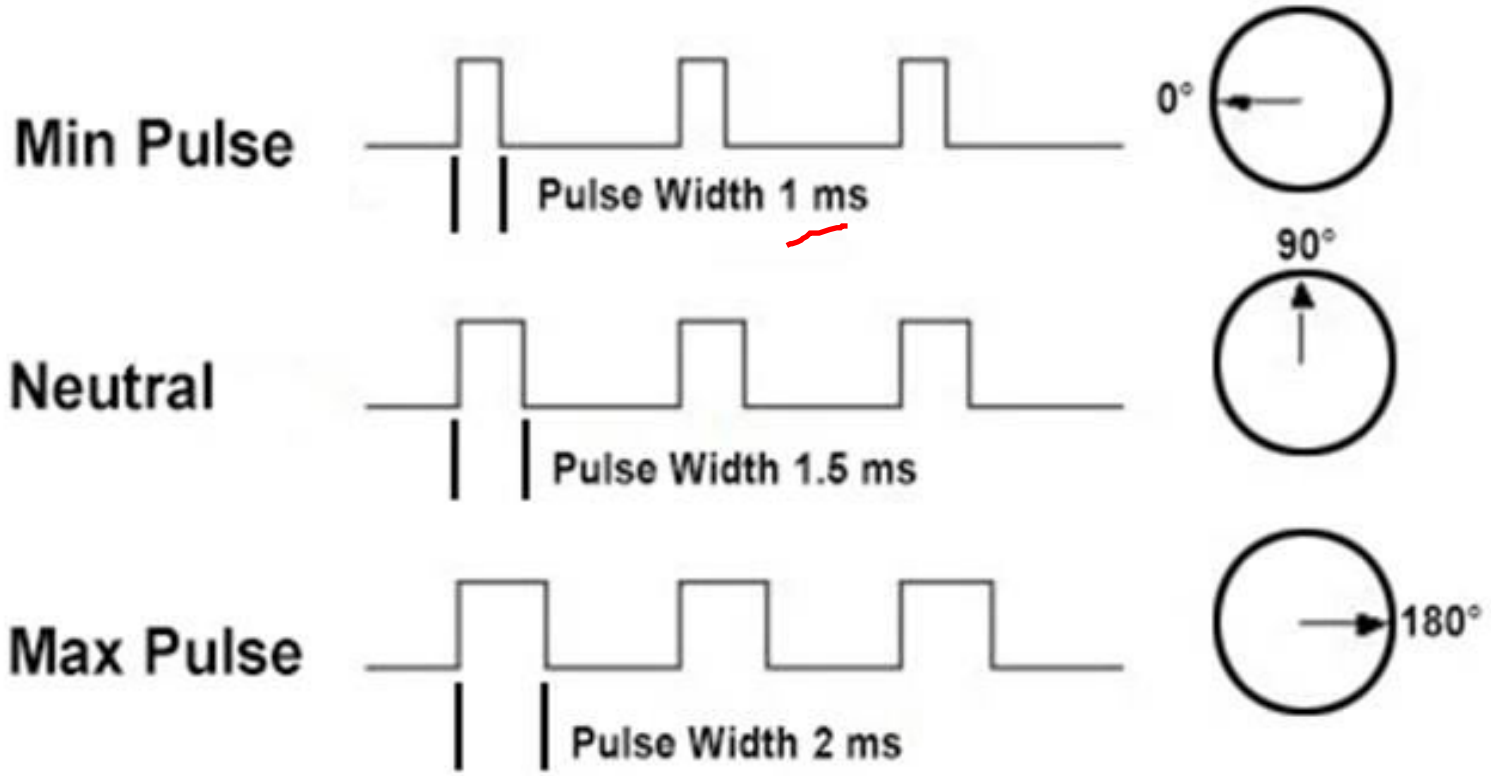
Controlling Servo Motor

- The control of servo motors is usually achieved using the pulse width modulation (PWM) technique, which involves varying the width of the pulse applied to the motor for a fixed amount of time.
- Servo motors usually have three wires: power, ground and the control signal.
- Most servos fixedly rotate between 0° and 180° - starting and ending at fixed points relative to the motor.



Controlling Servo Motor

- For most servos, a 1.5 ms pulse width will place the shaft in neutral position.
- Anything greater or less will move the shaft clockwise or counterclockwise.
- Typical servos can only move 90˚ in either direction from the neutral position.
- The PWM frequency for servos is typically in the range of 40-200 Hz, with most servos using 50 Hz.



Types of Servo Motor

- There are two main types of servo motors based on their current type.

DC servo motor

- As its name implies, a DC servo motor operates using direct current.
- They quickly respond to signals, but usually require more maintenance.

AC servo motor

- AC servo motors are controlled by alternating current and are designed to handle higher current surges than DC servo motors.
- They can achieve more torque and offer better control than their DC counterpart.
- These advantages make them ideal for heavy pieces of machinery, including CNC machines and robotic arms.

Application of Servo Motor

Servo motors are used in various industries for precision control:

- **Robotics**: servomotors are used in the robotics industry to control the angular movement and locations of the robotic arms.
- **Packaging Industries**: servo motors are used to control the movement of timing belts and other machine parts for labeling, bottling, and packaging.
- **Automatic doors**: servo motors control the opening and closing of automatic doors used in supermarkets and hospitals.
- **Automobile industry**: Servomotors are used to maintain vehicle speed, power steering, braking system etc..
- **Solar tracking system**: These are also used in the solar tracking system to correct the angle of the panel so that each solar panel stays to face the sun.

Application of Servo Motor

- **Cutting machines**: These are also used in metal forming and cutting machines to deliver specific motion control for milling machines.
- **Textile Industry**: Servo motor is used in Textiles to control spinning and weaving machines, knitting machines, and looms.
- **Conveyor belts**: These are used to start, move, and stop conveyor belts carrying the product. For instance, airport luggage delivery and collection.
- **Camera**: The servo motor is built into the camera to correct the lens of the camera to improve out-of-focus images.

However, the desirable performance of servo motors primarily depends on whether they are correctly sized for a particular application.

Advantages of Servo Motors

- High efficiency.
- High output power relative to their size.
- More constant torque at higher speed.
- Closed-loop control.
- Quiet operation.
- Highly reliable.
- High ratio of torque to inertia.
- High acceleration.

With the advancement of microprocessors and power transistors, AC servo motors are used more often due to their high accuracy control.

Disadvantages of Servo Motor

- The drawback is that it demands tuning to stabilize the feedback loop.
- If something breaks, the motor will be unreliable. Therefore, a protection circuit is required.
- The overall system cost and installation cost are higher than that of a stepper motor due to the need for feedback components.
- It would require a complex controller to provide the encoder and electronic support.