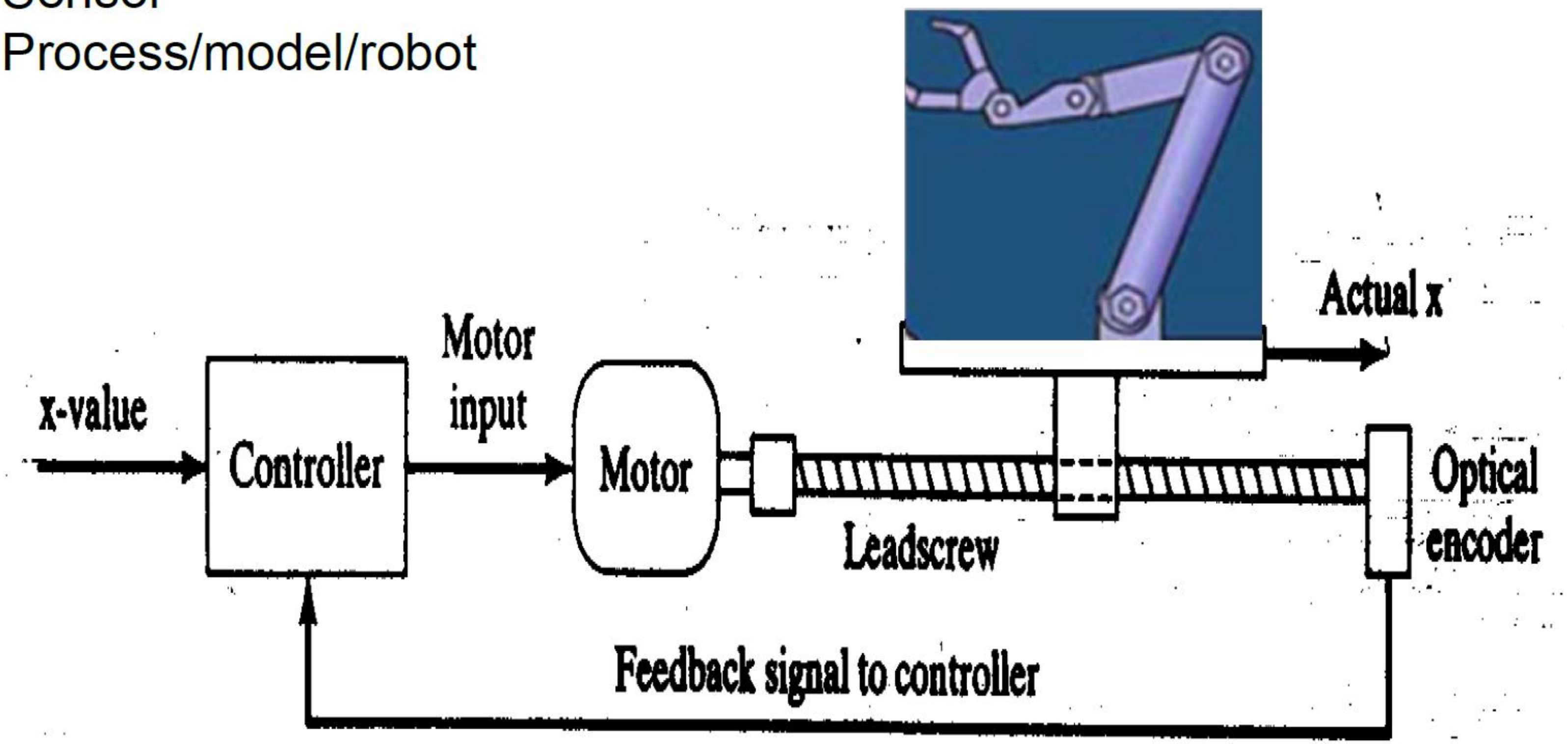
Introduction to Robotics

ISS3180-01

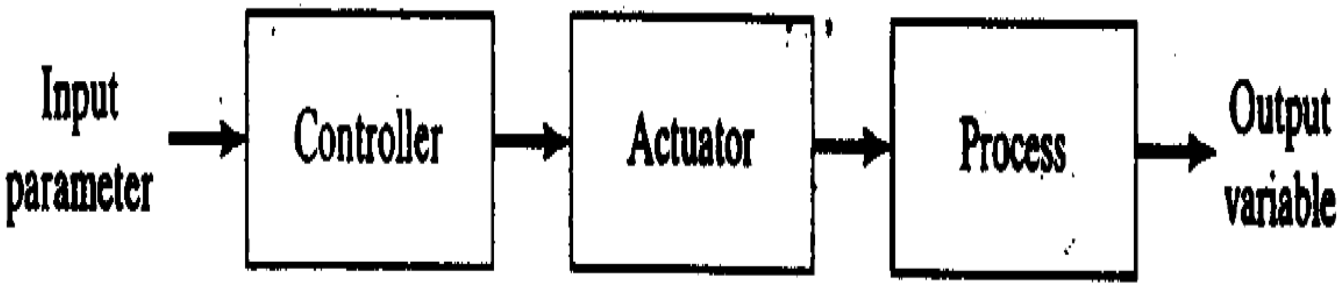
Professor Mannan Saeed Muhammad

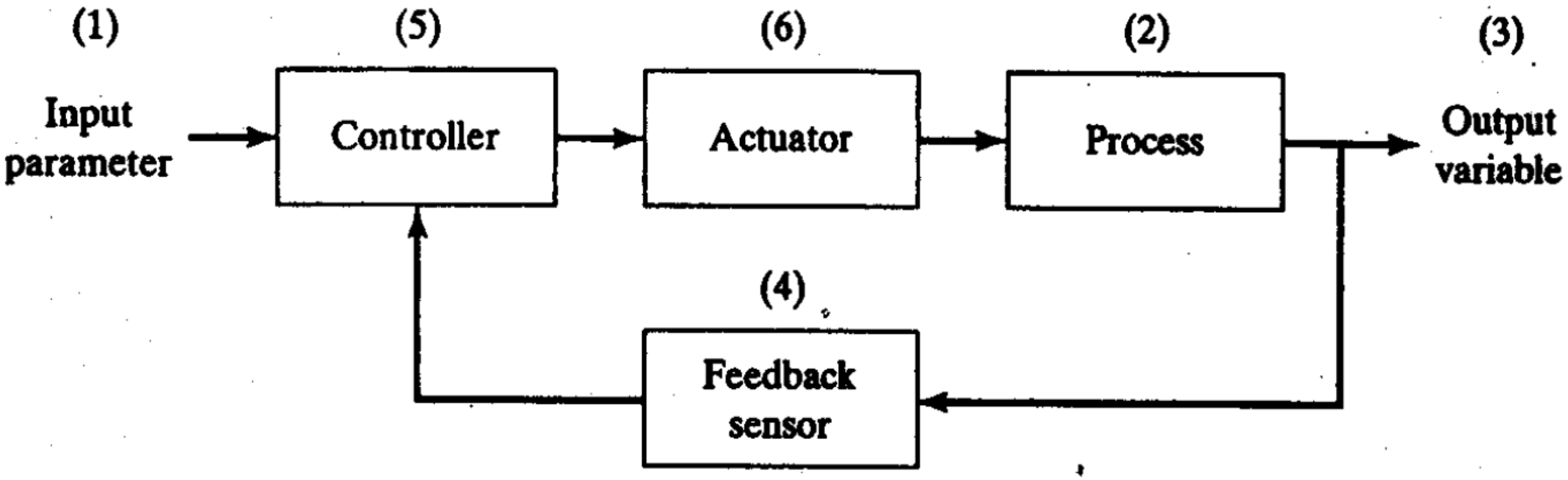
Sub-systems in robot control

- Controller
- Actuator
- Sensor
- Process/model/robot



Open loop and closed loop





Basic elements

- Sensors
- Actuators
- Controllers
- System model

General Classification of Sensors

- **Internal sensors:** required for basic working of the system (e.g. position, velocity,).
- **External sensors:** interaction with the environment (vision, force, …).

Sensors used for closed loop position control: Internal sensors

- **Position**
- **Velocity**
- **Acceleration**

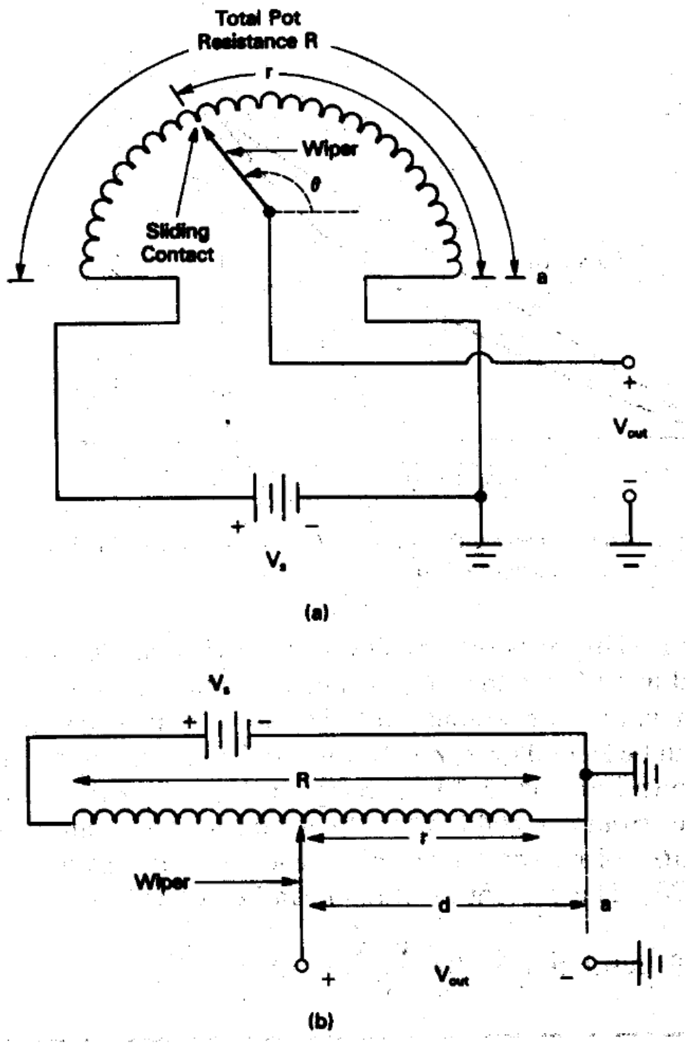
- **e.g. potentiometers, encoders, LVDT (**Linear Variable Differential Transformer**), Tachometers, Accelerometers**

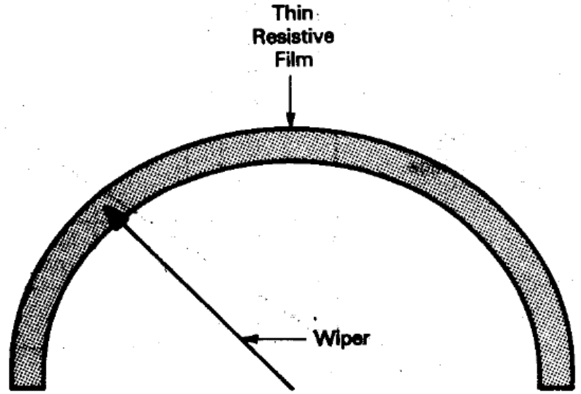
Sensors for interaction with the environment: External sensors

- **Touch**
- **Force**
- **Pressure**
- **Slip**
- **Proximity**
- **Vision**

- e.g. on/off switches, ultrasonic, force sensor, hall effect, inductive sensor, piezo sensor

Position Sensor : Potentiometer





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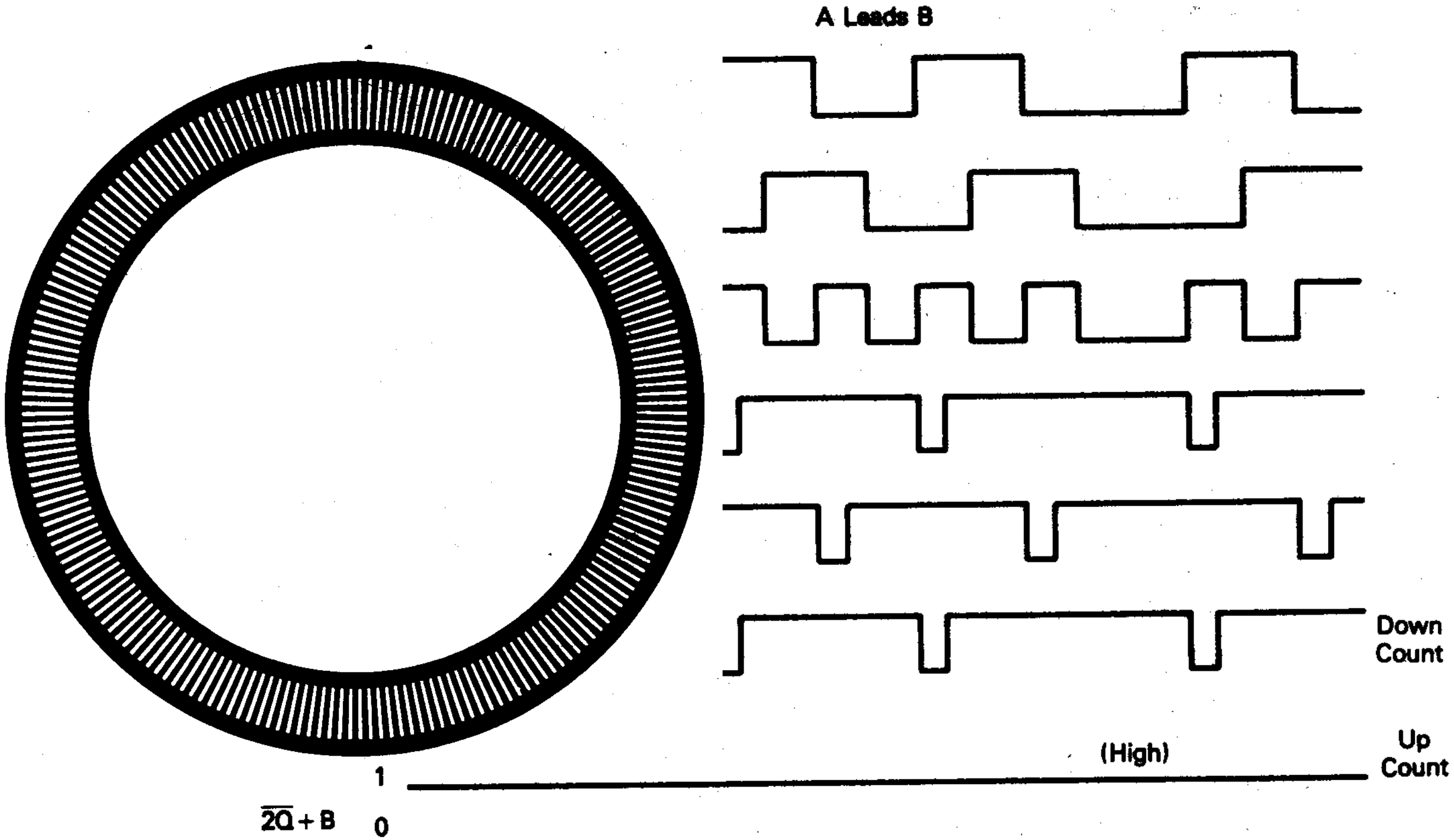
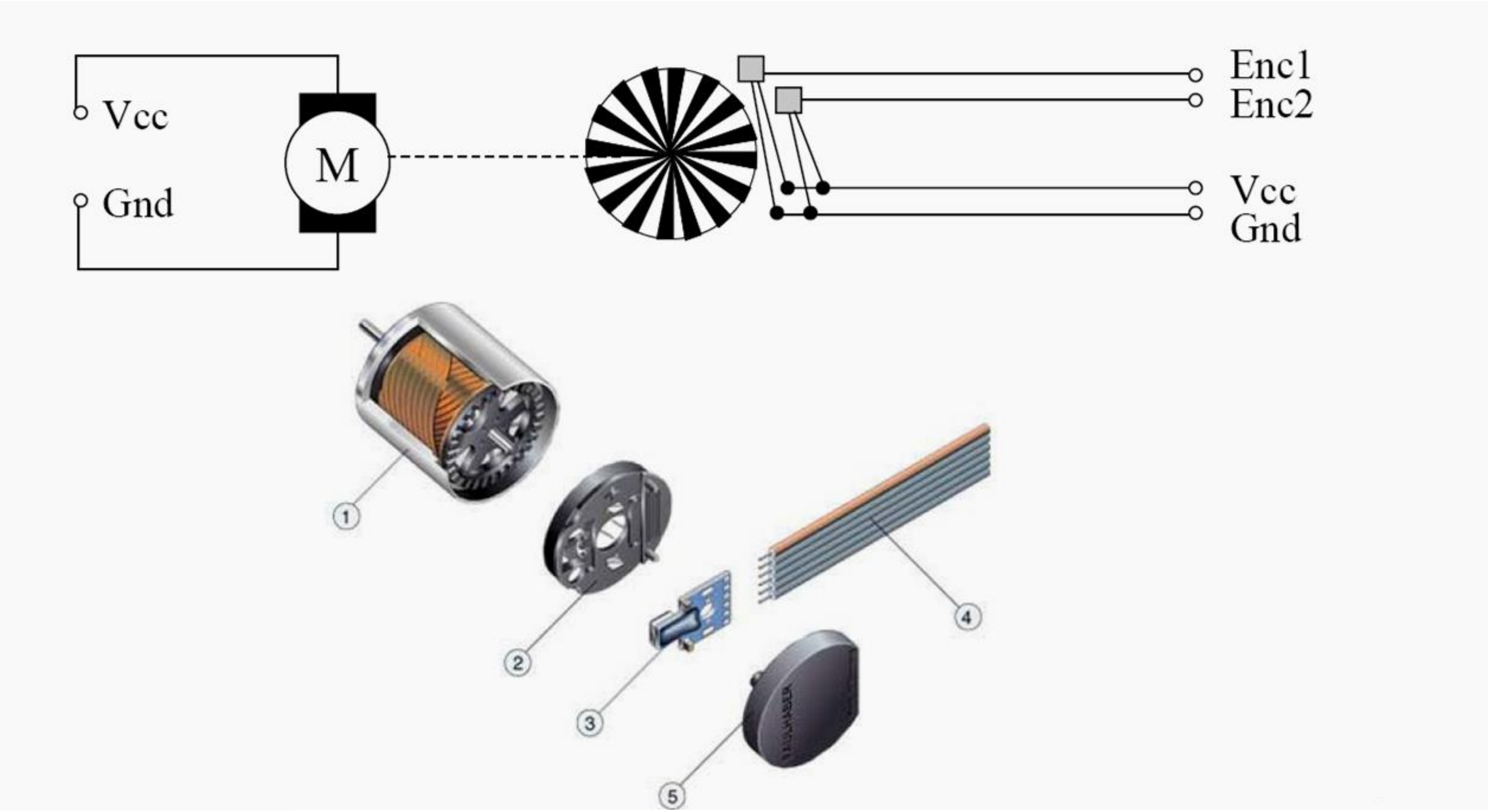
Position sensor: Incremental Encoder



Motor and Encoder



Motor and Encoder

- Motor speed determined by:

  supplied voltage

- Motor direction determined by:

  polarity of supplied voltage

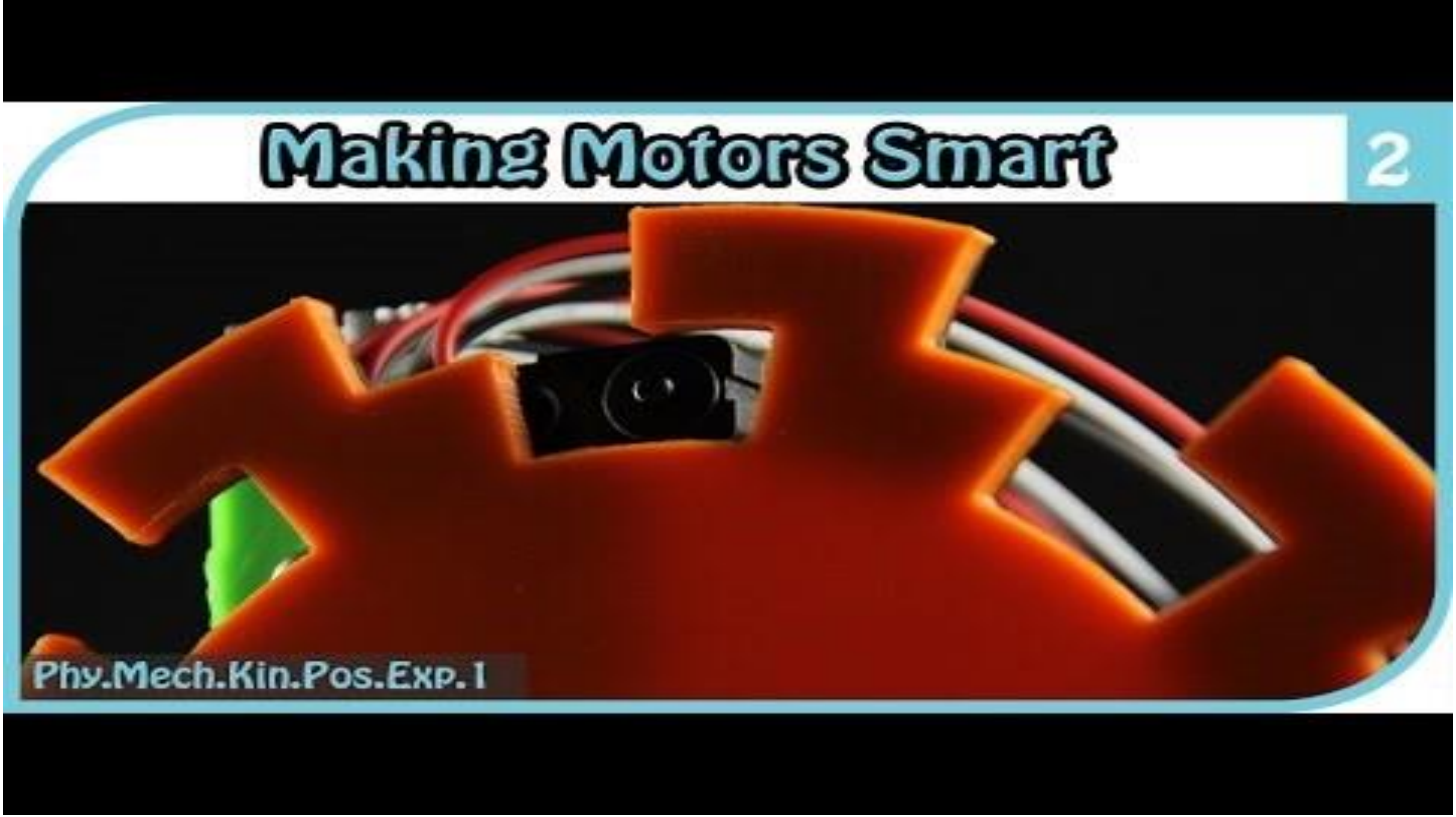
- Difficult to generate analog power signal

(1A ..10A) directly from microcontroller

→ external amplifier (pulse-width modulation)

Motor and Encoder

- Encoder disk is turned once for each rotor revolution
- Encoder disk can be optical or magnetic
- Single detector can determine speed
- Dual detector can determine speed and direction
- Using gears on motor shaft increases encoder accuracy



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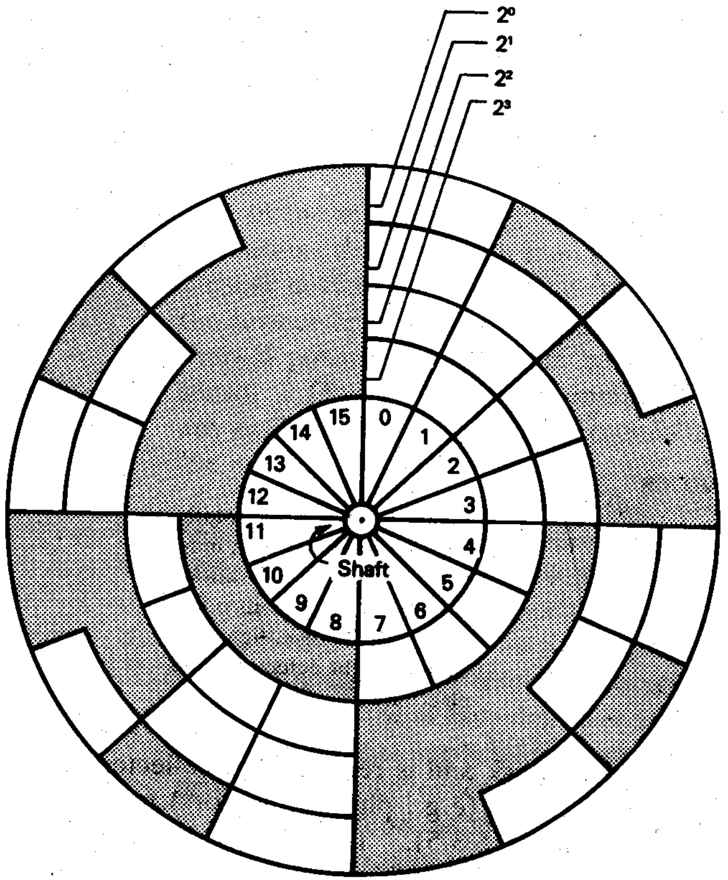
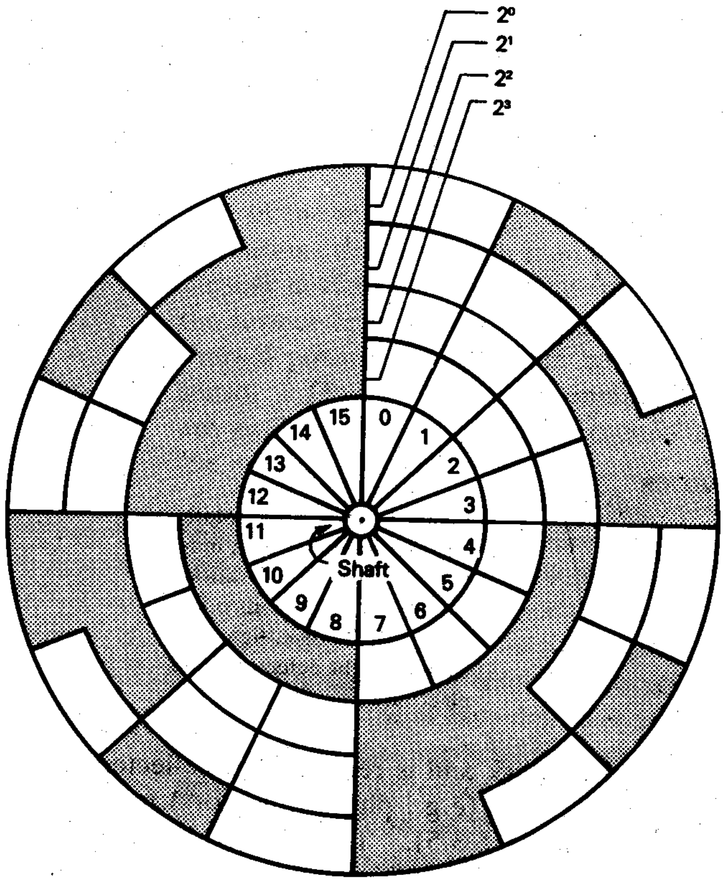
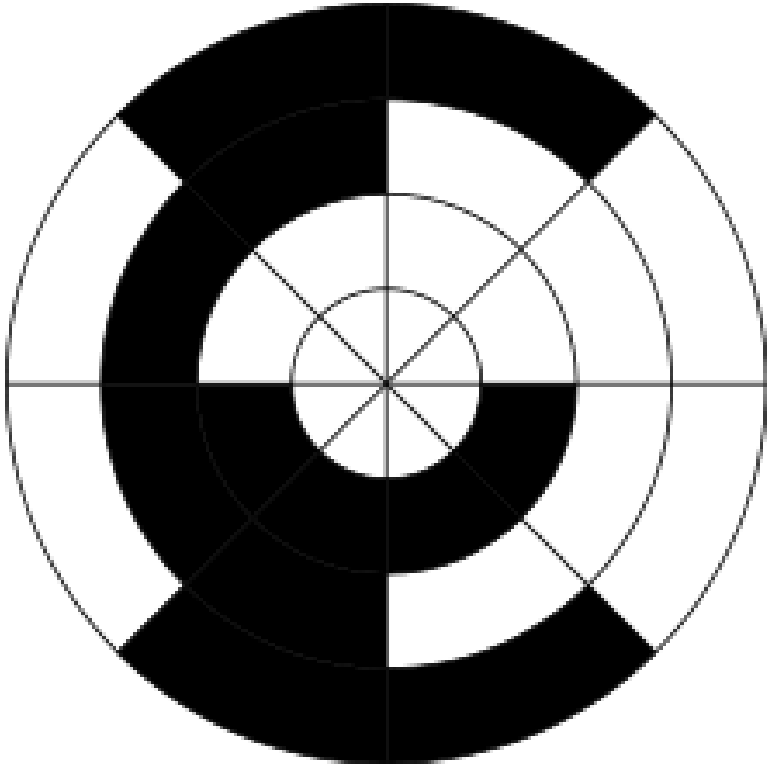
Position sensor : Absolute encoder

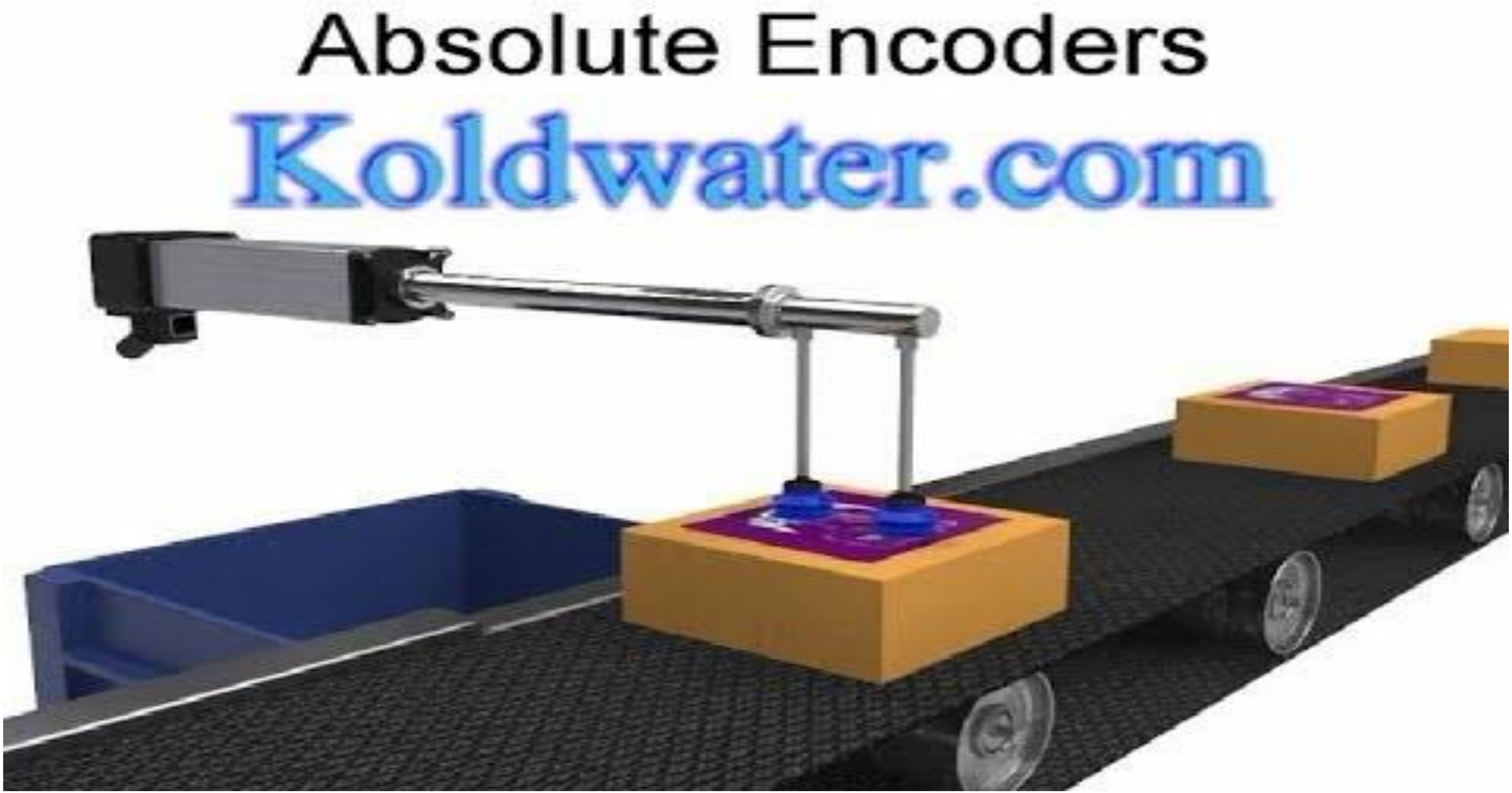


Position sensor : Grey encoder





Decimal	Binary	Gray
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111
11	1011	1110
12	1100	1010
13	1101	1011
14	1110	1001
15	1111	1000



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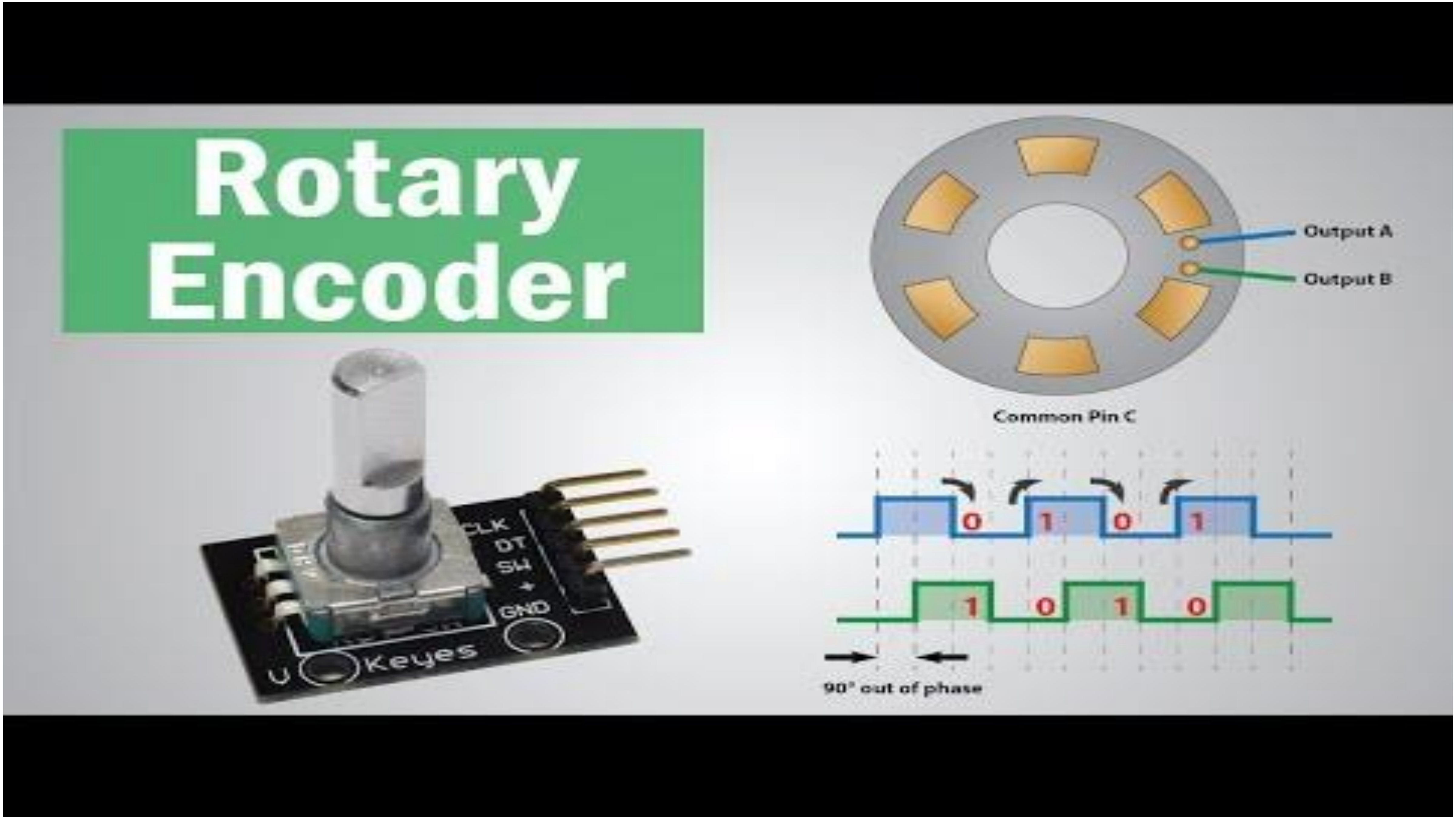

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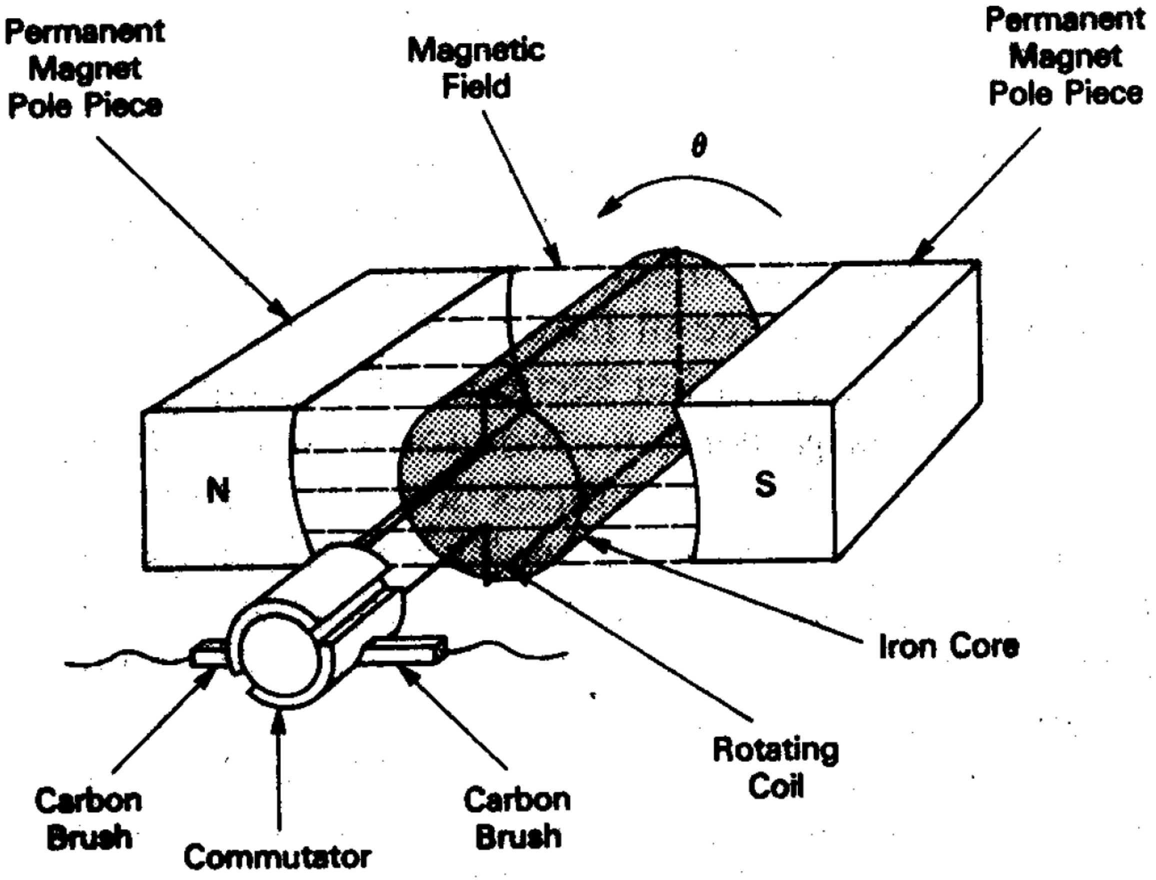
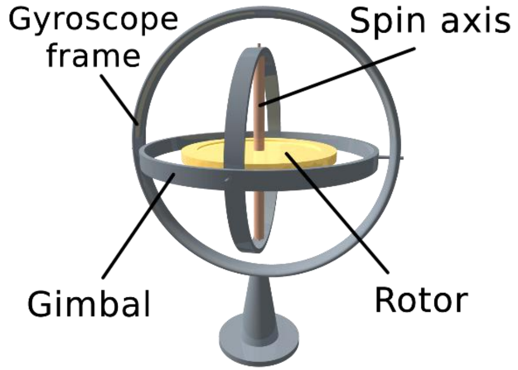
Velocity and acceleration sensors



Gyroscopic Sensor: Measure angles

- A gyroscope
  - device used for measuring or maintaining orientation and angular velocity.
  - It is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by itself.
  - When rotating, the orientation of this axis is unaffected by tilting or rotation of the mounting, according to the conservation of angular momentum.
- Gyroscopes based on other operating principles also exist, such as the microchip-packaged MEMS gyroscopes found in electronic devices, solid-state ring lasers, fibre optic gyroscopes, and the extremely sensitive quantum gyroscope.
- MEMS gyroscopes are popular in some consumer electronics, such as smartphones.



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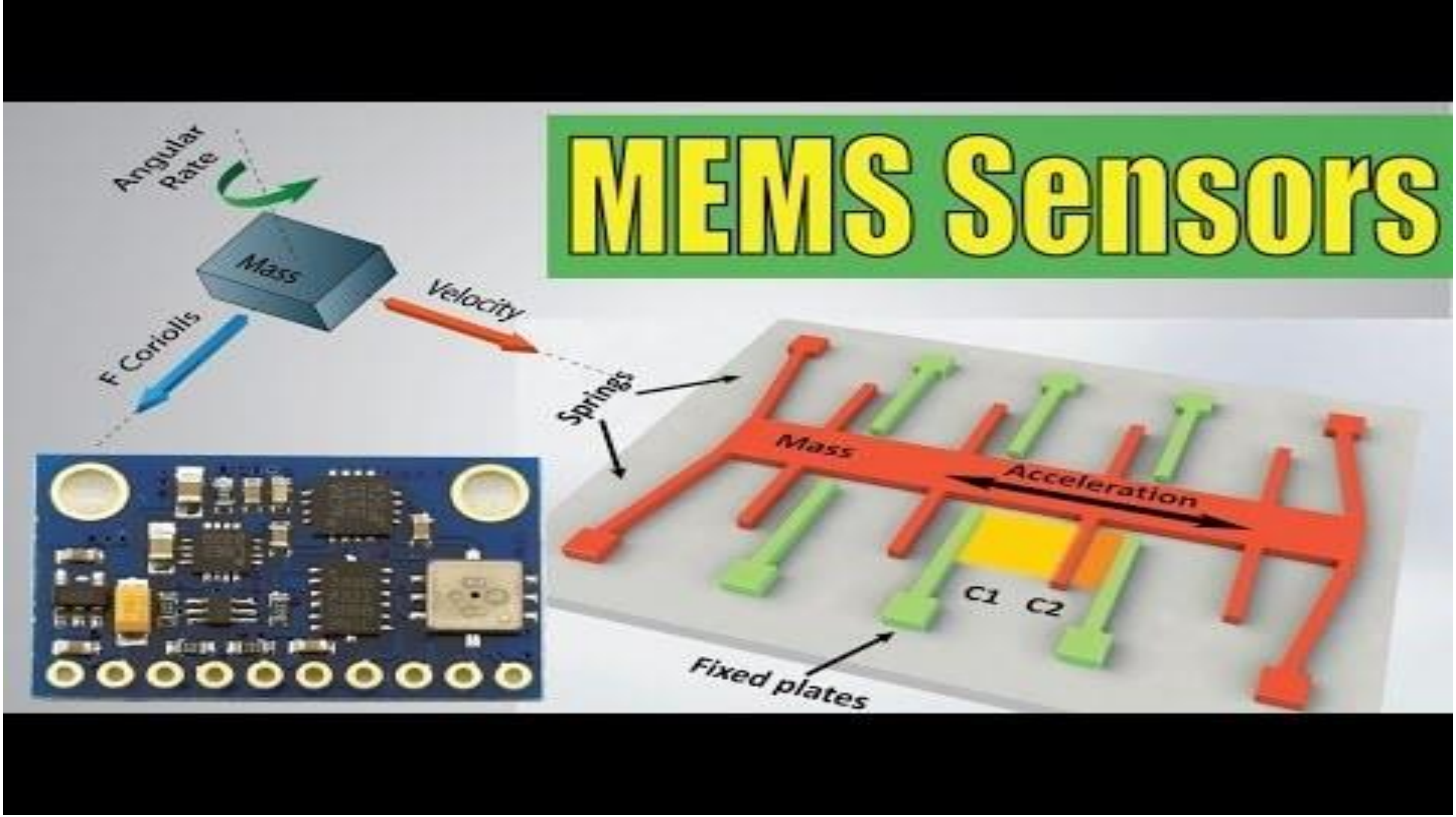

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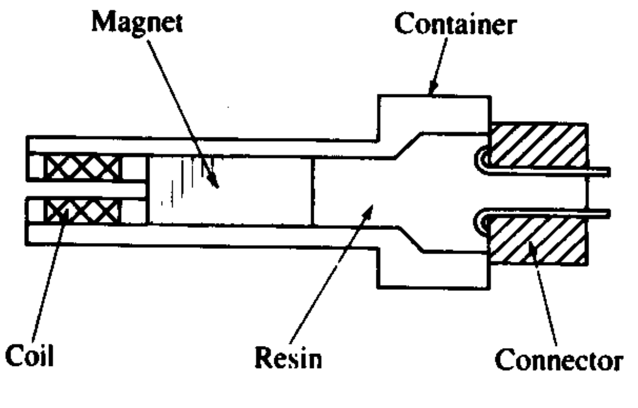
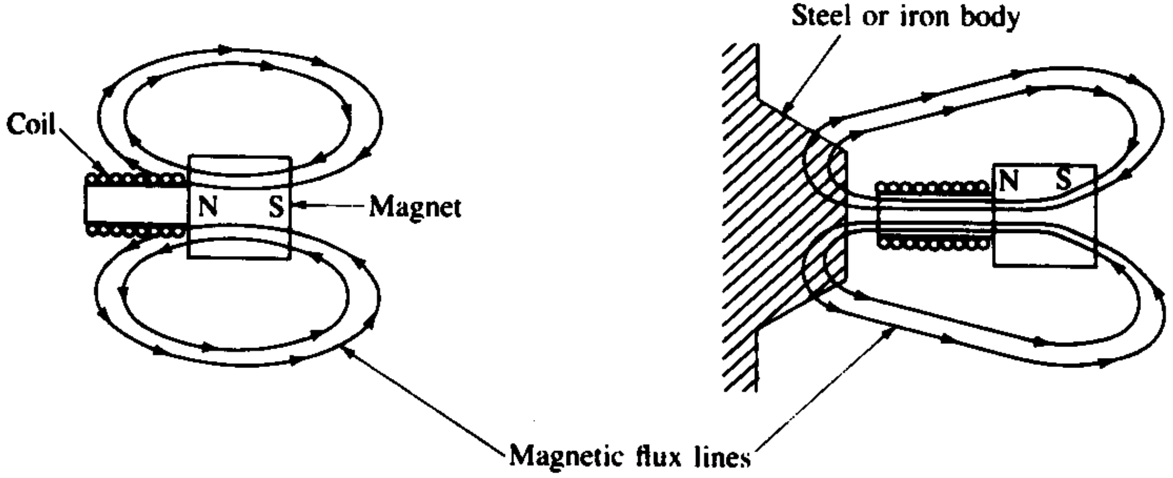
Other Sensors

- **On /Off switches**
- **Emitter / receiver pairs**
- **Thermal / pressure sensors**

Proximity sensor : Inductive sensor

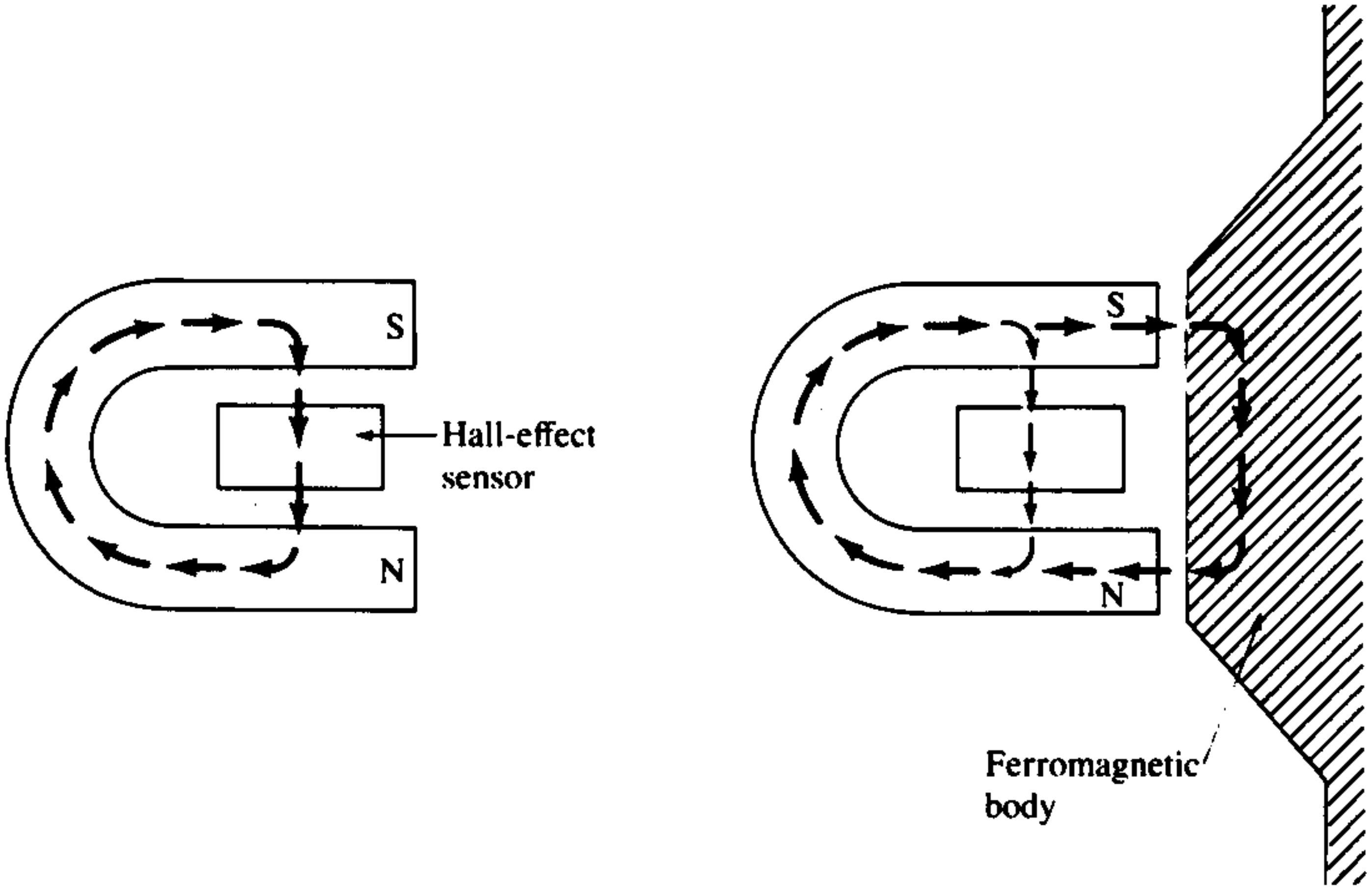


(a)



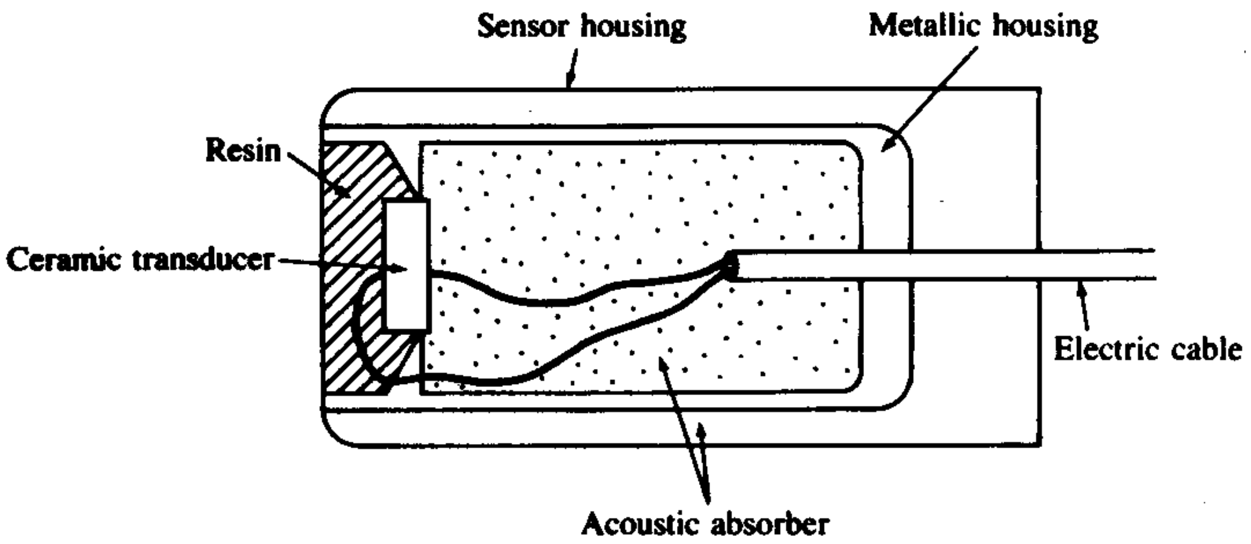
(b) (c)

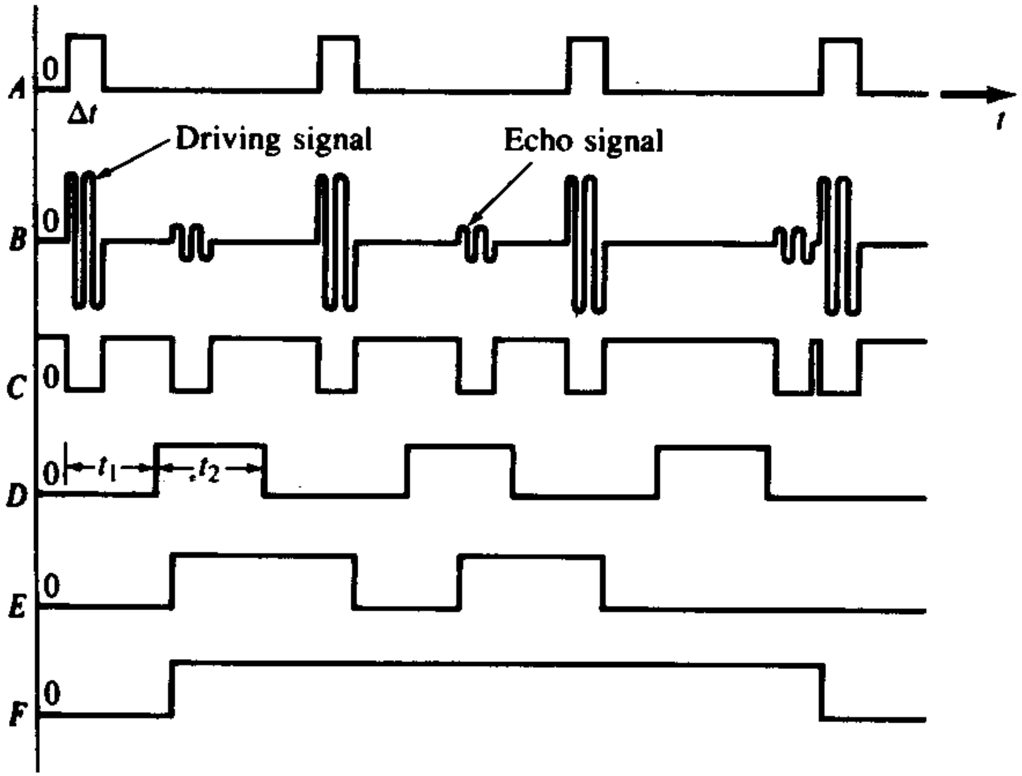
Proximity sensor: Hall effect sensor



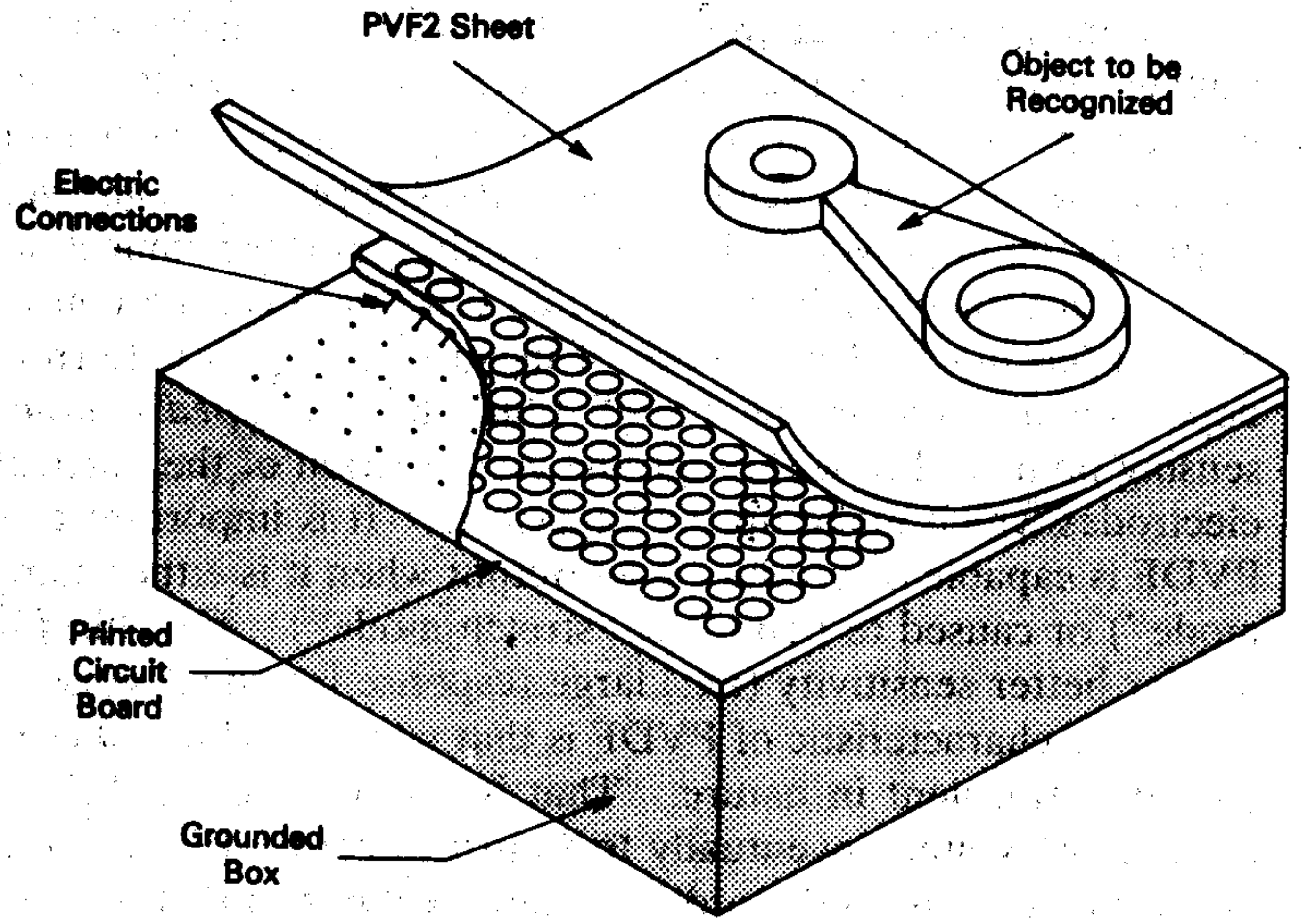
(a) (b)

Range sensor : Ultrasonic sensor

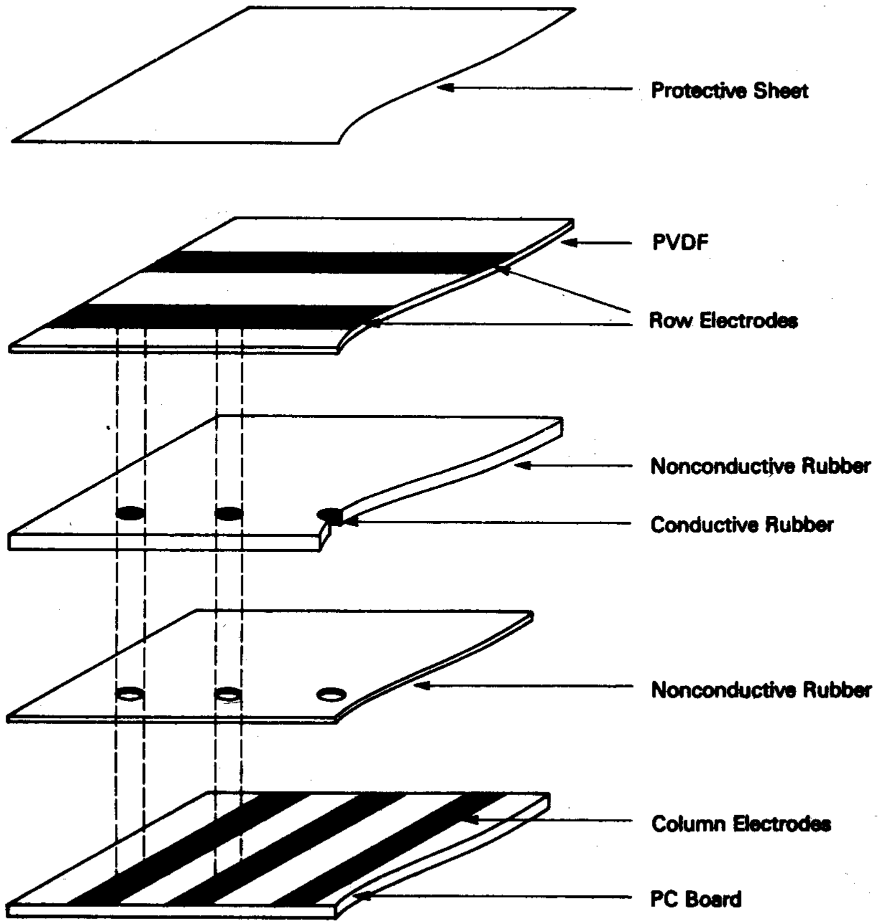


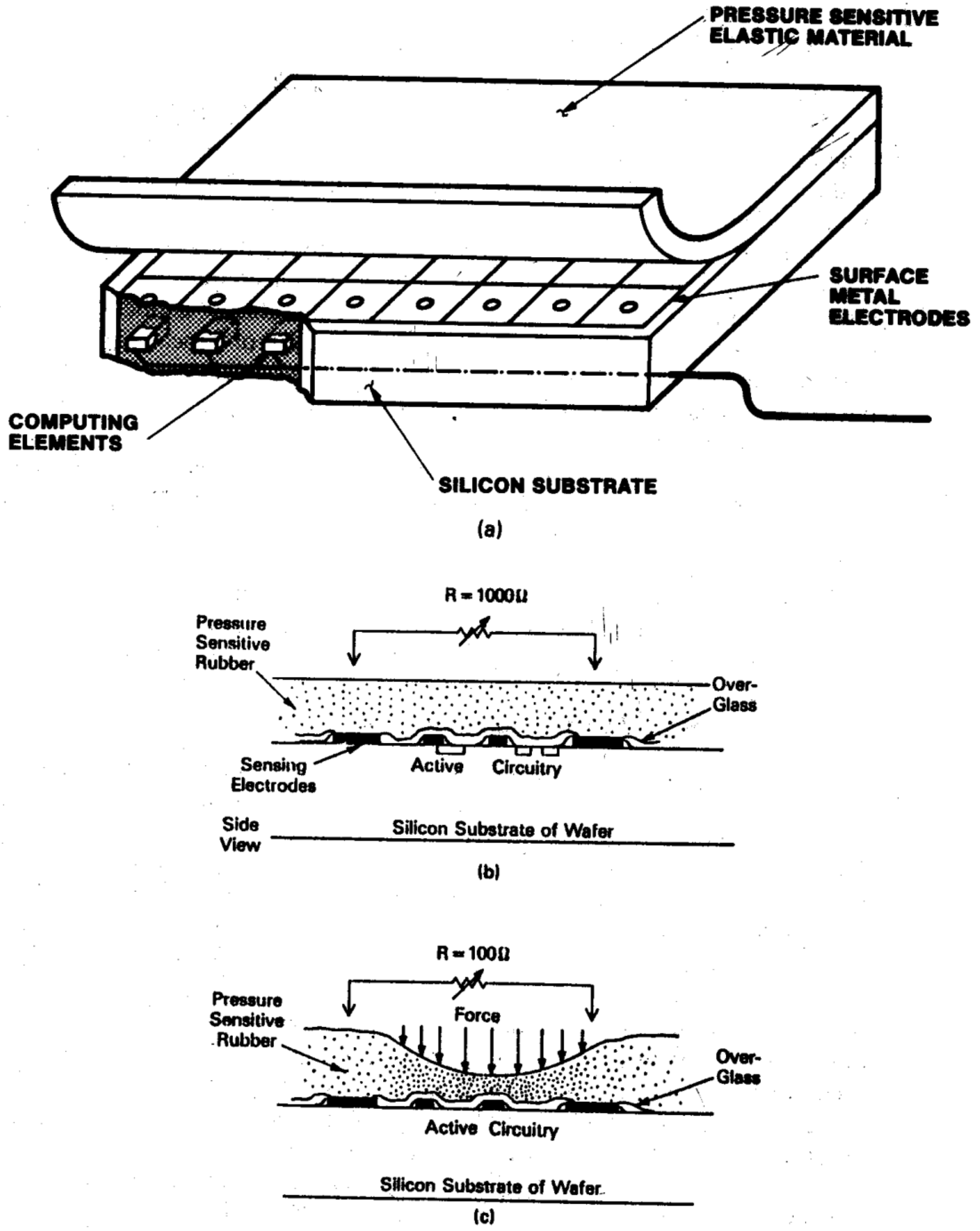


Touch sensor

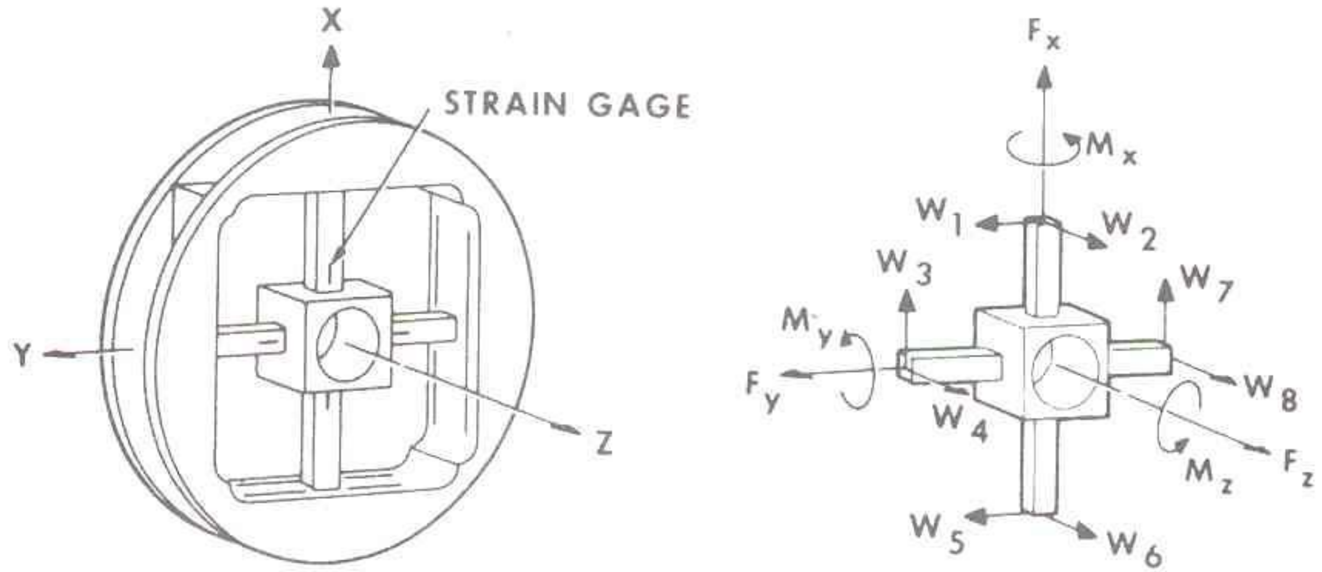


Pressure sensor





Force sensors



TRANSFORMATION MATRIX UNDER IDEAL CONDITIONS

FORCES AND TORQUES REFERENCED TO X-Y-Z SENSOR COORDINATES

$$\begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & k_{13} & 0 & 0 & 0 & k_{17} & 0 \\ k_{21} & 0 & 0 & 0 & k_{25} & 0 & 0 & 0 \\ 0 & k_{32} & 0 & k_{34} & 0 & k_{36} & 0 & k_{38} \\ 0 & 0 & 0 & k_{44} & 0 & 0 & 0 & k_{48} \\ 0 & k_{52} & 0 & 0 & 0 & k_{56} & 0 & 0 \\ k_{61} & 0 & k_{63} & 0 & k_{65} & 0 & k_{67} & 0 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \\ W_5 \\ W_6 \\ W_7 \\ W_8 \end{bmatrix}$$

FORCES SENSED AT SPOKE ELEMENTS

Mapping

Actuator Space

Joint Space

End effector Space

Actuators

- ***Electrical*** **: stepper motors, DC servo motors**
- ***Pneumatic*** **: air pressure**
- ***Hydraulic*** **: fluid pressure (oil pressure).**

- ***Advanced actuators*** **: ultrasonic motors, artificial muscles, molecular motors.**

Actuators

- Motor
- H-Bridge
- Pulse-Width-Modulation (PWM)
- Servos
- Other robotic actuators

Actuator Types

- Electrical
- Hydraulic
- Pneumatic
- Others

Actuators

- Actuators can be built in may different ways, most prominently:
  - electrical motors
  - pneumatics and valves.
- In this course we will only deal with electrical motors
- In past we built pneumatic robots which you can still find in the lab.
  - We will build them again after purchasing air compressor
- My first robot was very strong and it was hydraulic. It pissed hot oil at students in Warsaw.

Servo System

Servo is mechanism based on feedback control.

The controlled quantity is mechanical.

Properties of Servo

- high maximum torque/force allows high (de)acceleration
- high zero speed torque/force
- high bandwidth provides accurate and fast control
- works in all four quadrants
- robustness

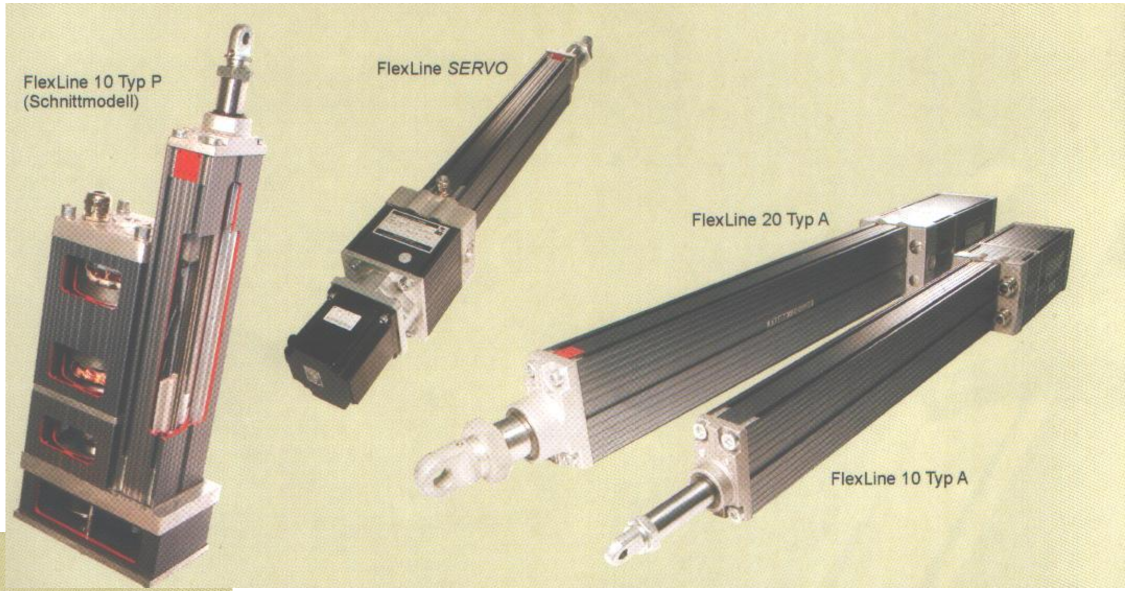
Electrical Actuators

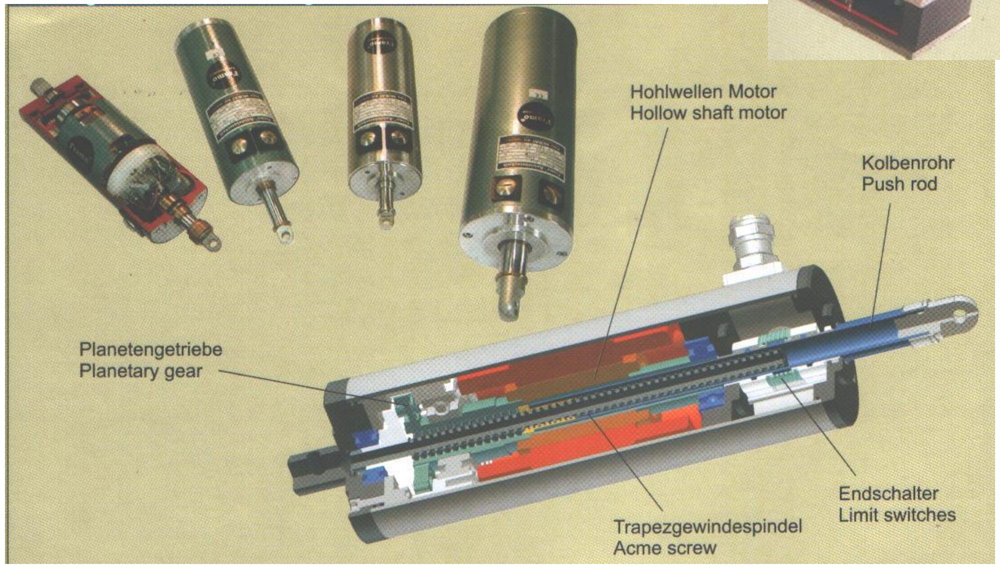
- easy to control
- from mW to MW
- normally high velocities 1000 - 10000 rpm
- several types
- accurate servo control
- ideal torque for driving
- excellent efficiency
- autonomous power system difficult

Electric actuators

- Mainly rotating but also linear ones are available

- linear movement with gear or with real linear motor



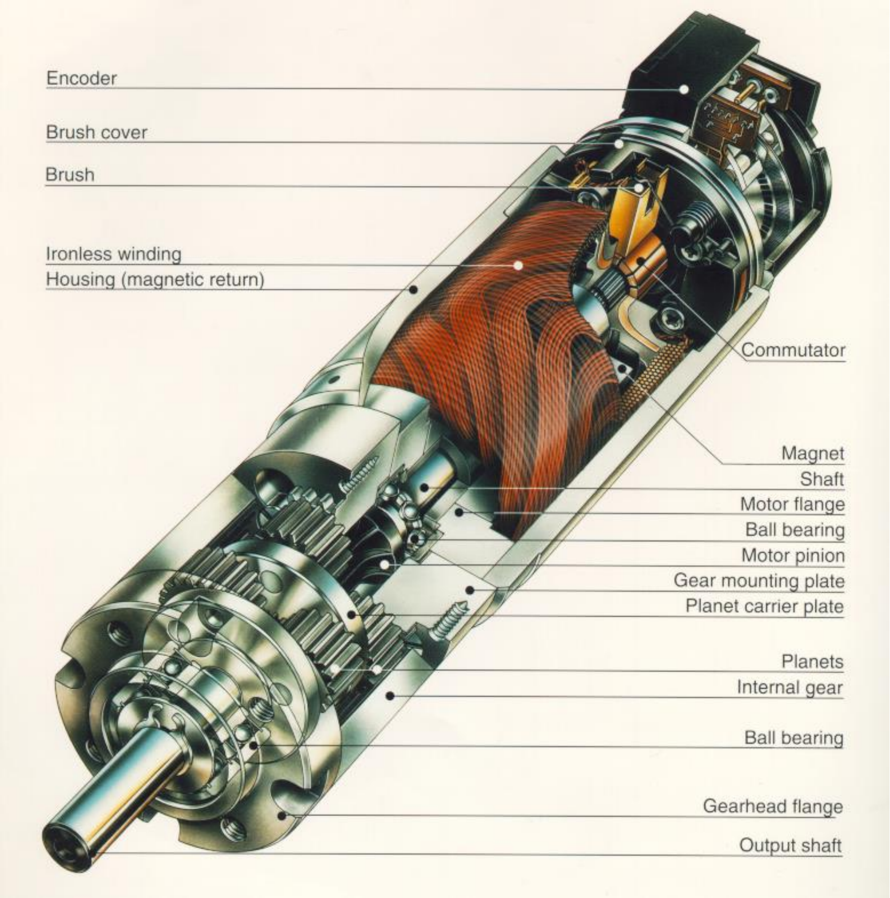


Electrical Actuator Types

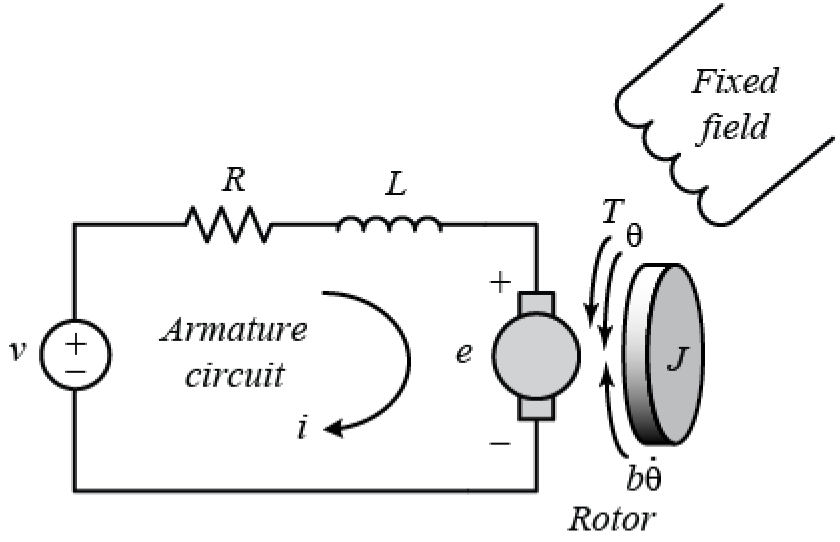
- DC-motors
- brushless DC-motors
- asynchronous motors
- synchronous motors
- reluctance motors (stepper motors)

DC-Motors

- simple, cheap
- easy to control
- 1W - 1kW
- can be overloaded
- brushes wear
- limited overloading on high speeds



DC Motor Equations



Electrical part:

$$e_a(t) = R_a i_a(t) + K_b \frac{d\theta_m(t)}{d(t)}$$

Mechanical load:

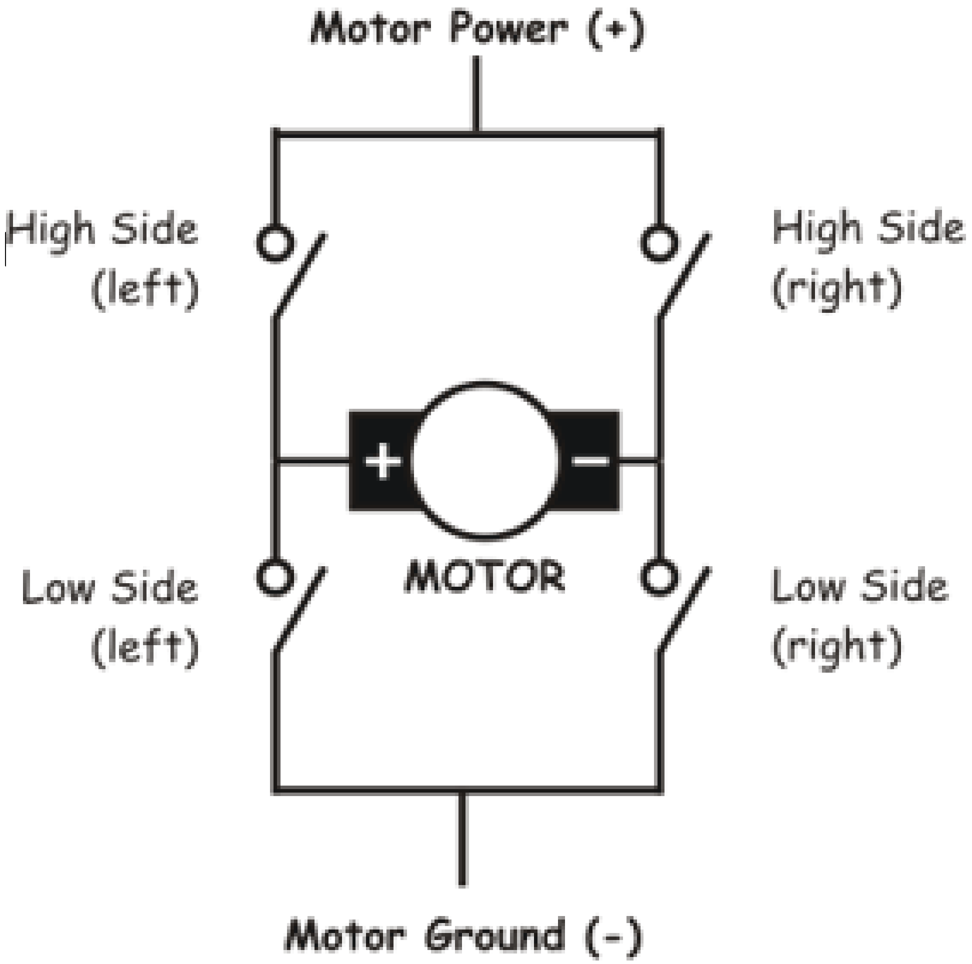
$$T_m(t) - D_a + \left(\frac{N1}{N2}\right)^2 D_L \frac{d\theta_m(t)}{dt} = J_a + \left(\frac{N1}{N2}\right)^2 J_L \frac{d^2\theta_m(t)}{dt^2}$$

The electrical − mechatronic part:

$$T_m = K_a i_a(t)$$

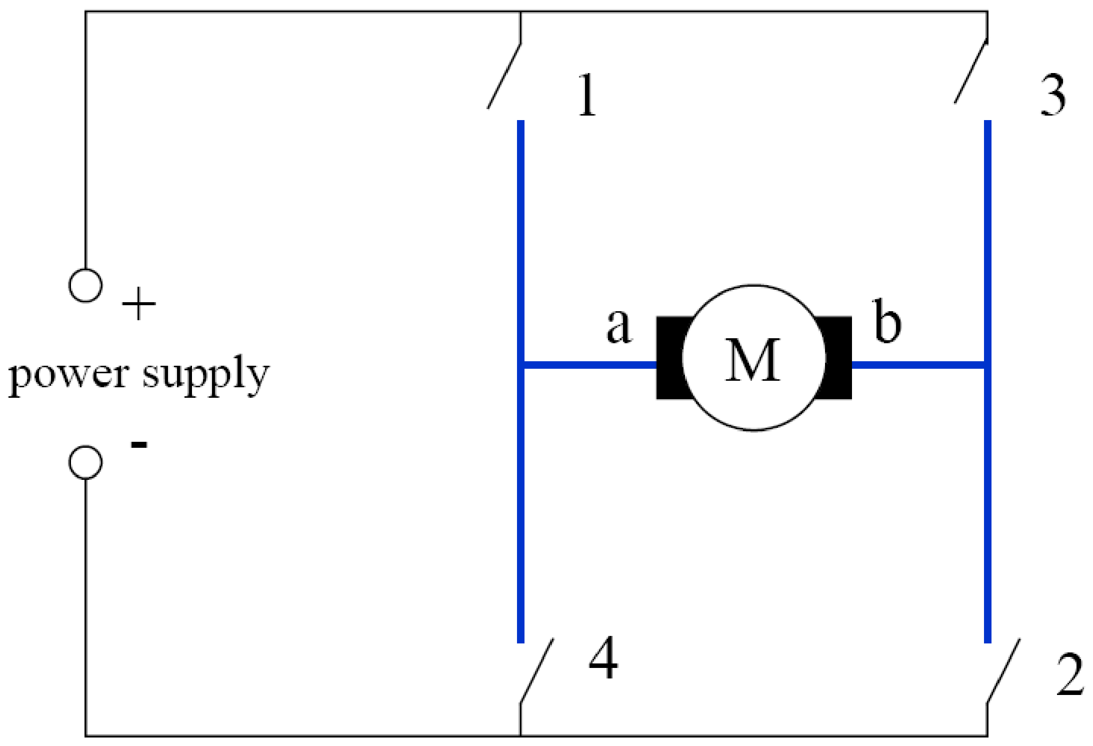
DC-motor control

- Controller + H-bridge
- PWM-control
- Speed control by controlling moto
- Efficient small components
- PID control



H-Bridge

Allows a motor to be driven in both directions



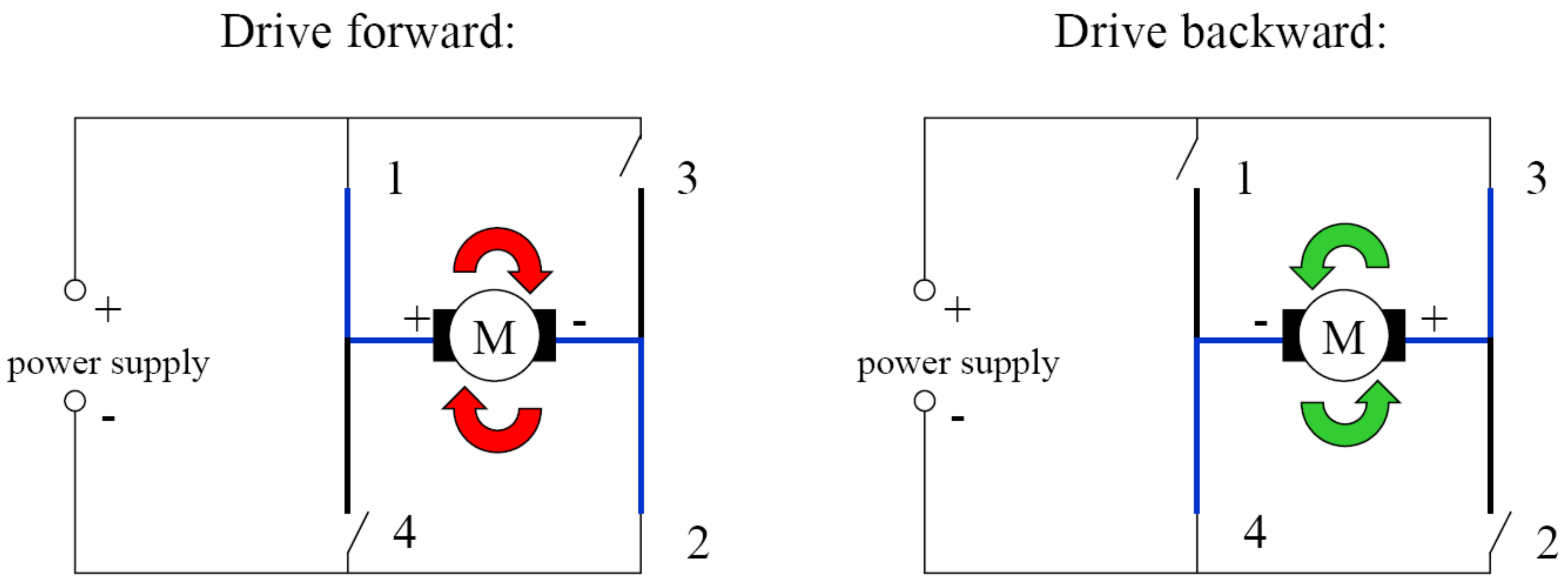
Drive forward:

- Close 1 and 2

Drive backward:

- Close 3 and 4

H-Bridge



H-Bridge

- **Hardware Implementation with Microcontroller:**
- 2 Digital output pins from microcontroller,

  [one at Gnd, one at Vcc] feed into a power amplifier

- *Alternative:* use only 1 digital output pin plus one inverter, then feed into a power amplifier

Power Amplifier

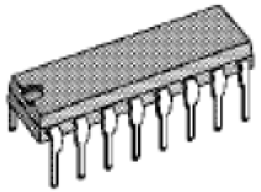
SGS-THOMSON MICROELECTRONICS

L293D

PUSH-PULL FOUR CHANNEL DRIVER WITH DIODES

PRELIMINARY DATA

- 600mA. OUTPUT CURRENT CAPABILITY PER CHANNEL
- 1.2A PEAK OUTPUT CURRENT (NON REPETITIVE) PER CHANNEL
- ENABLE FACILITY
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 1.5v (HIGH NOISE IMMUNITY
- INTERNAL CLAMPS DIODES



Powerdip 12+2+2

ORDERING NUMBER : L293D

DESCRIPTION

The L293D is a monolithic integrated high voltage, high current four channel vriver designed to accept standard DTL or TTL logic levels and drive inductive loads (such as relays solenoides, DC and stepping motors) and switching power transistors.

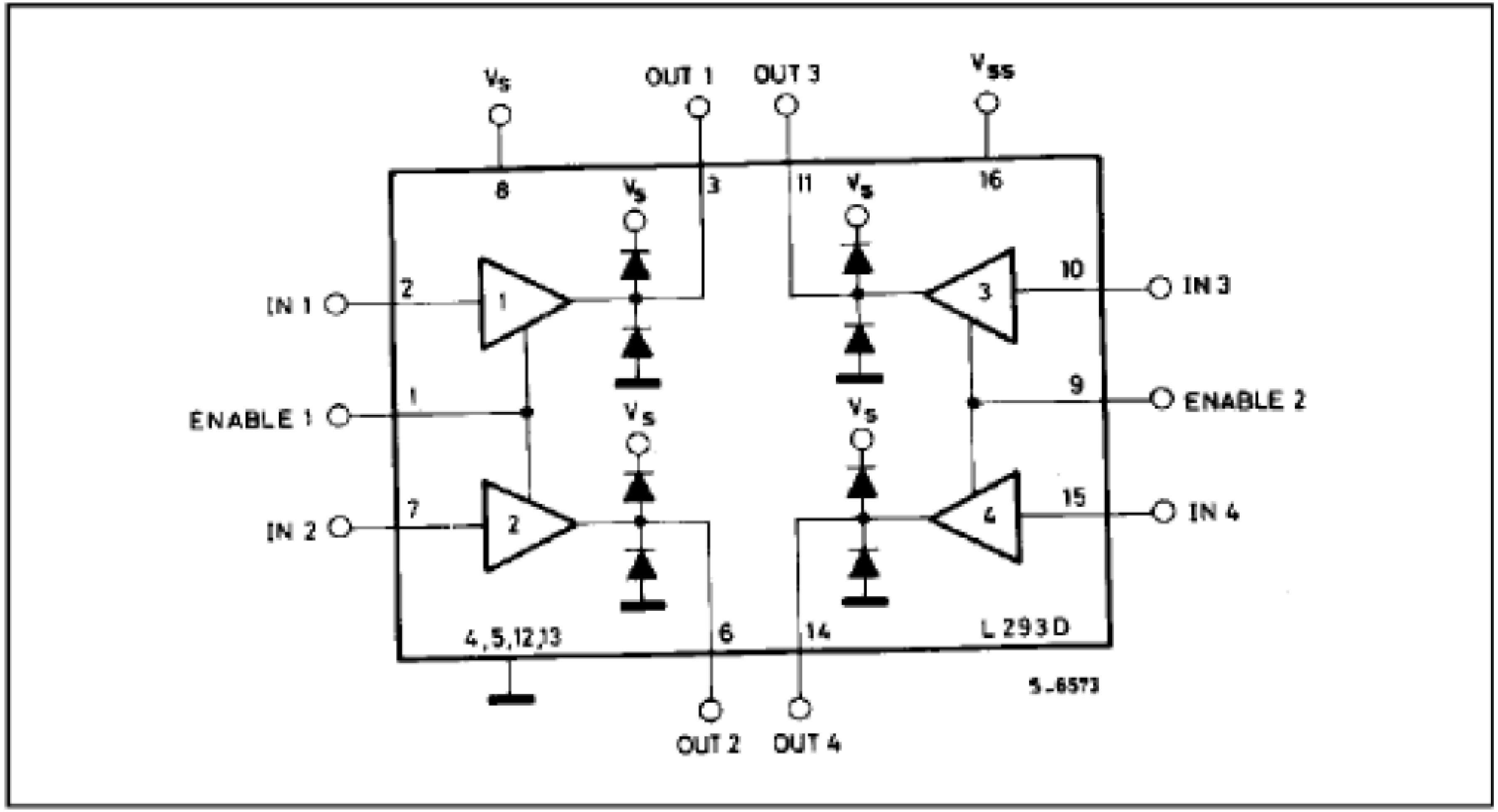
To simplify use as two bridges is pair of channels is equiped with an enable input. A separate supply innput is provited formthe logic, allowing operation at a low voltage and internal clamp diodes are included.

This device is suitable for use in switching applications at frequencies up to 5 KHz.

The L293D is assembled in a 16 lead plastic packege which has 4 center pins connected together and used for heatsinking.

Power Amplifier

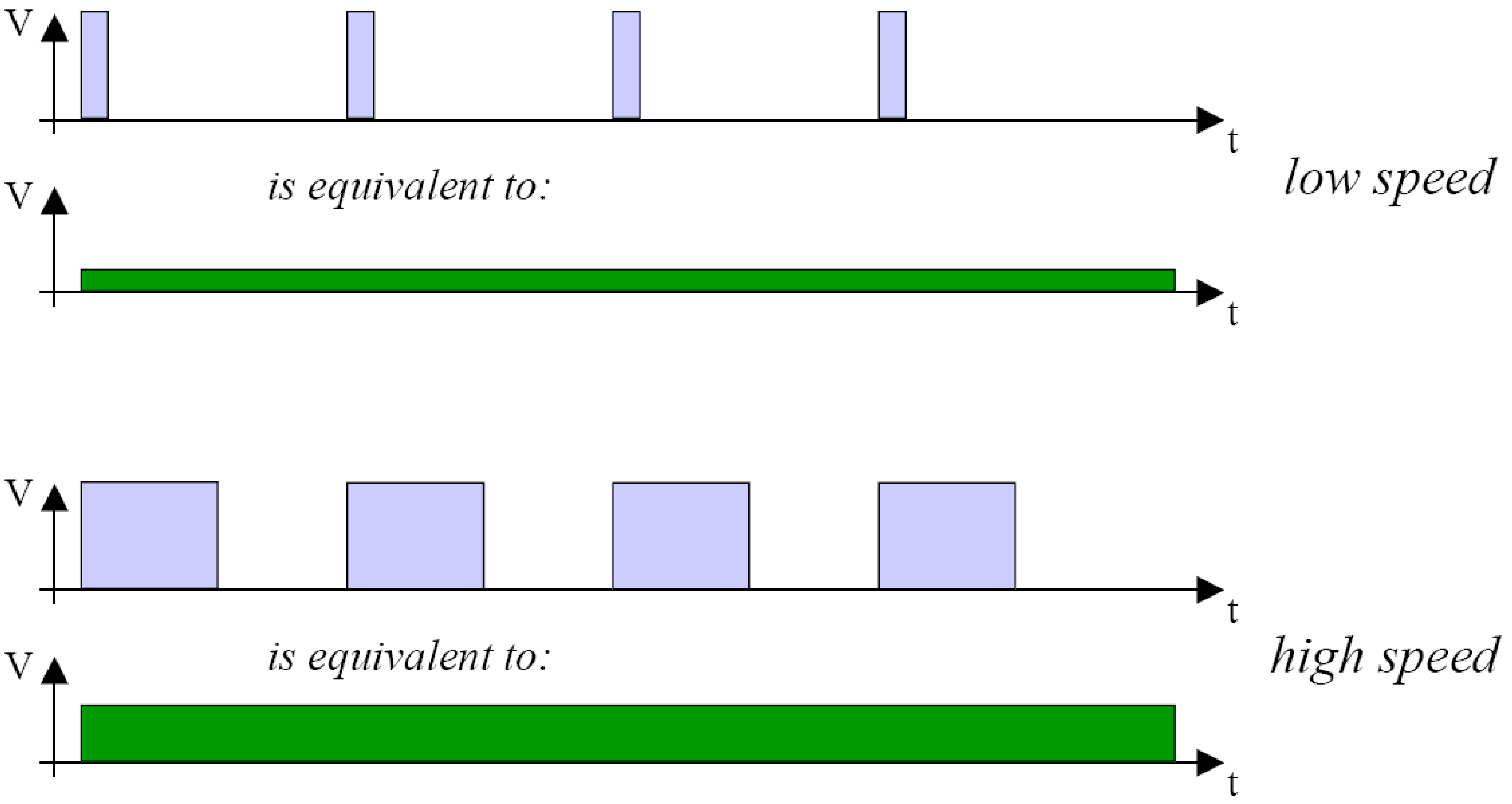
BLOCK DIAGRAM



Pulse-Width Modulation

- A/D converters are used for reading analog sensor signals
- Why **not** use D/A converter for motor control?
  - Too expensive (needs power circuitry)
  - Better do it by **software**, switching power on/off in intervals
  - This is called “**Pulse-Width Modulation**” or **PWM**

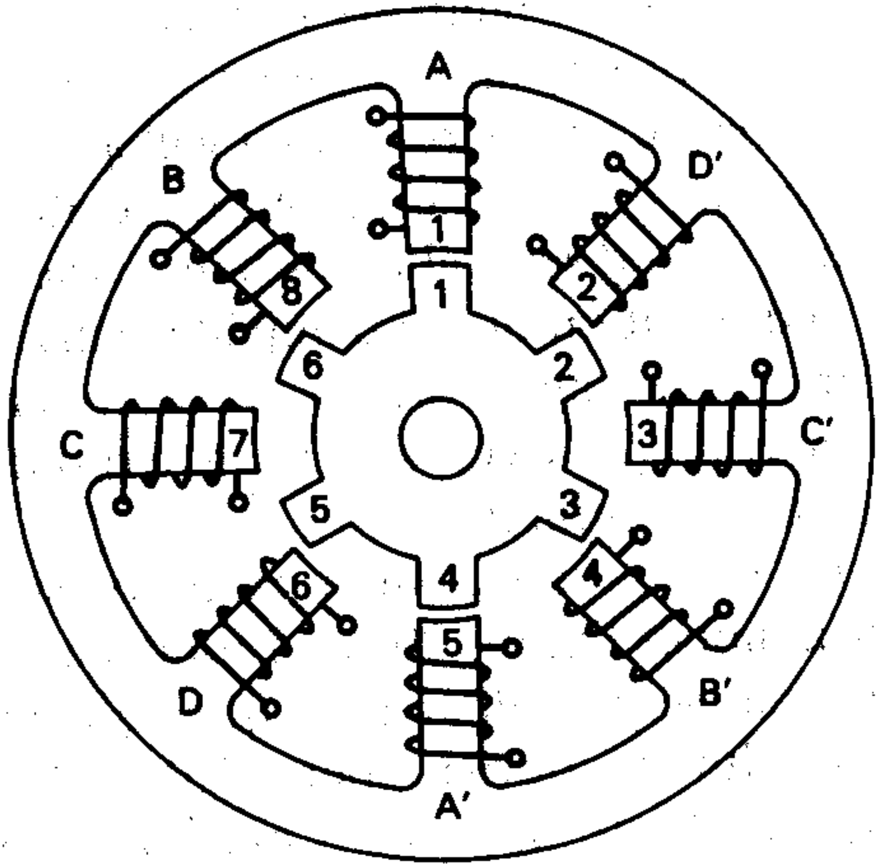
Pulse-Width Modulation



Pulse-Width Modulation

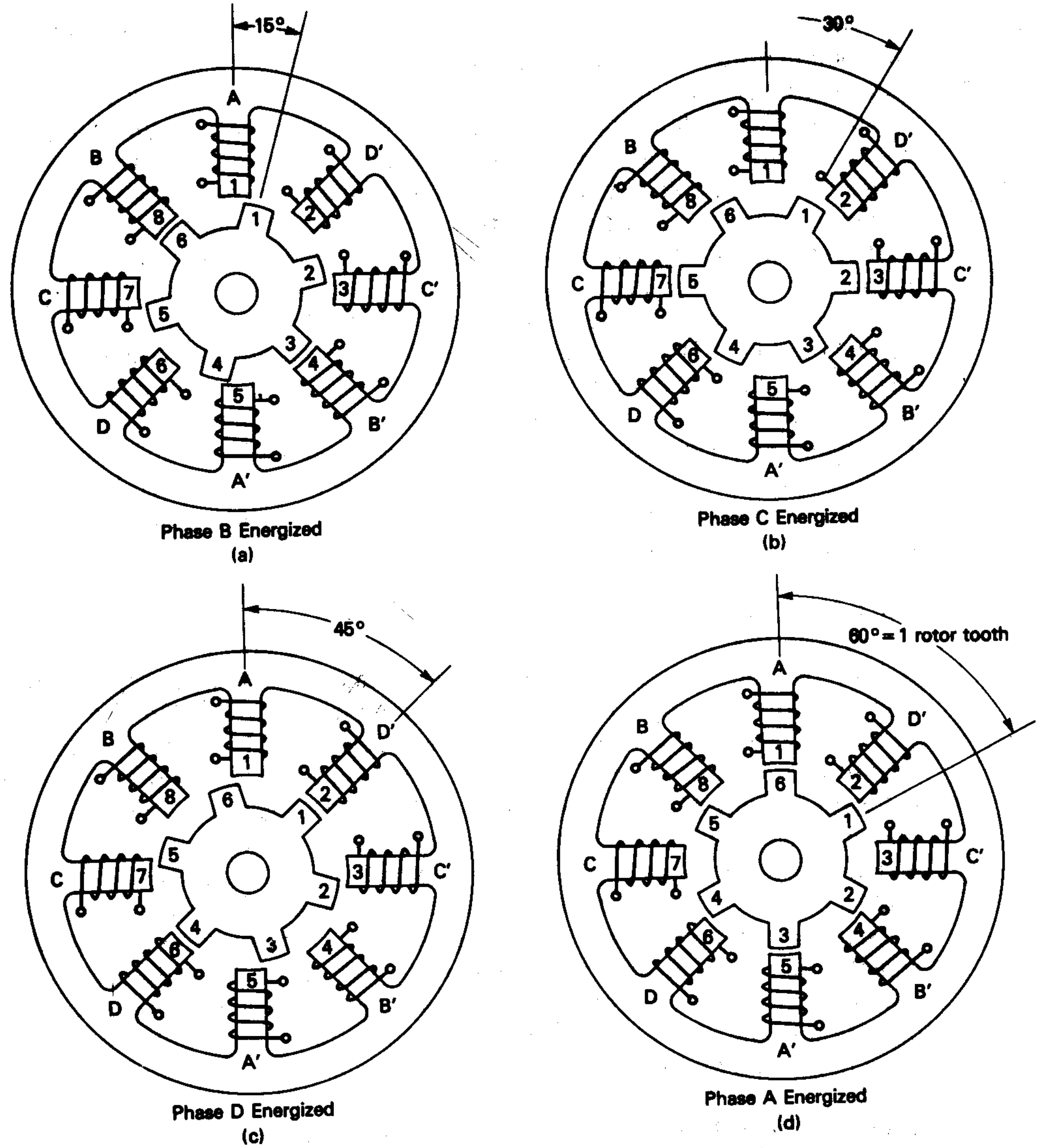
- **How does this work?**
  - We do not change the supplied voltage
  - Power is switched on/off at a certain pulse ratio matching the desired output power
- Signal has very high frequency (e.g. 20kHz)
- Motors are relatively slow to respond
  - The only thing that counts is the supplied power
  - ⇒ **Integral** (Summation)
- Pulse-Width Ratio = t_{on} / t_{period}

Stepper motors :
Variable reluctance, permanent magnet

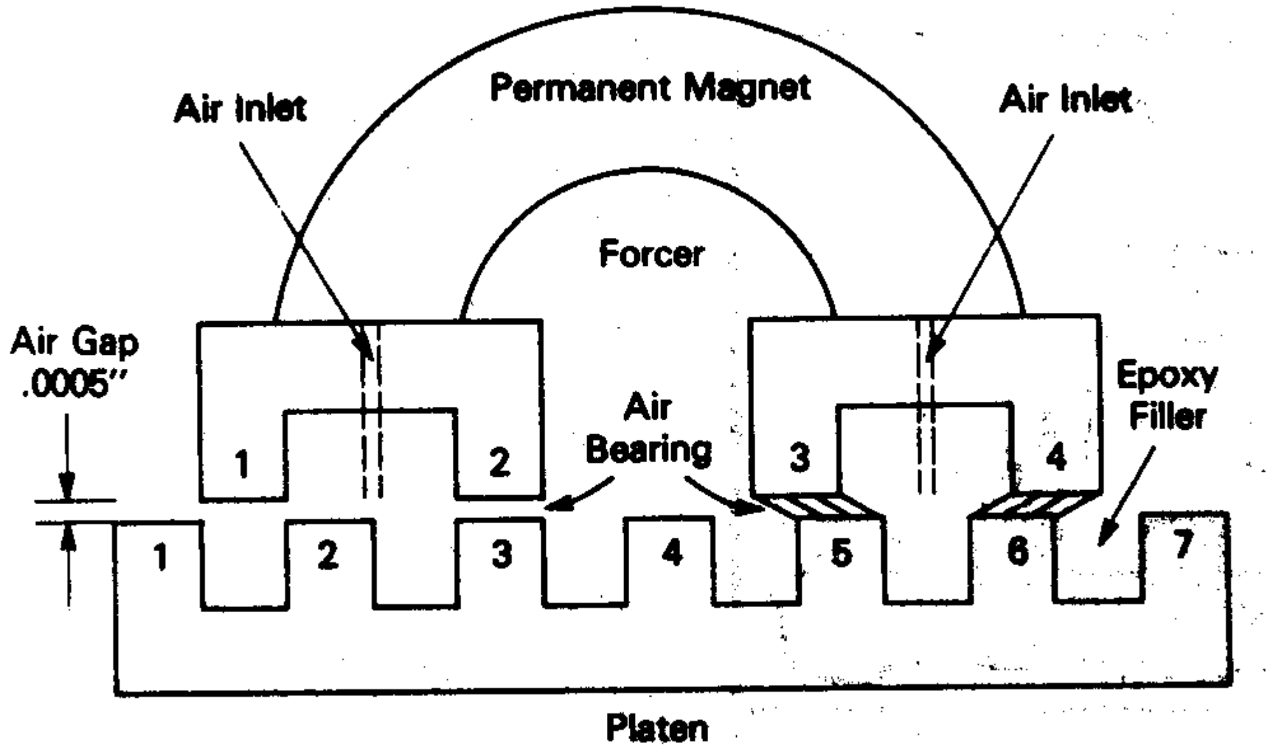


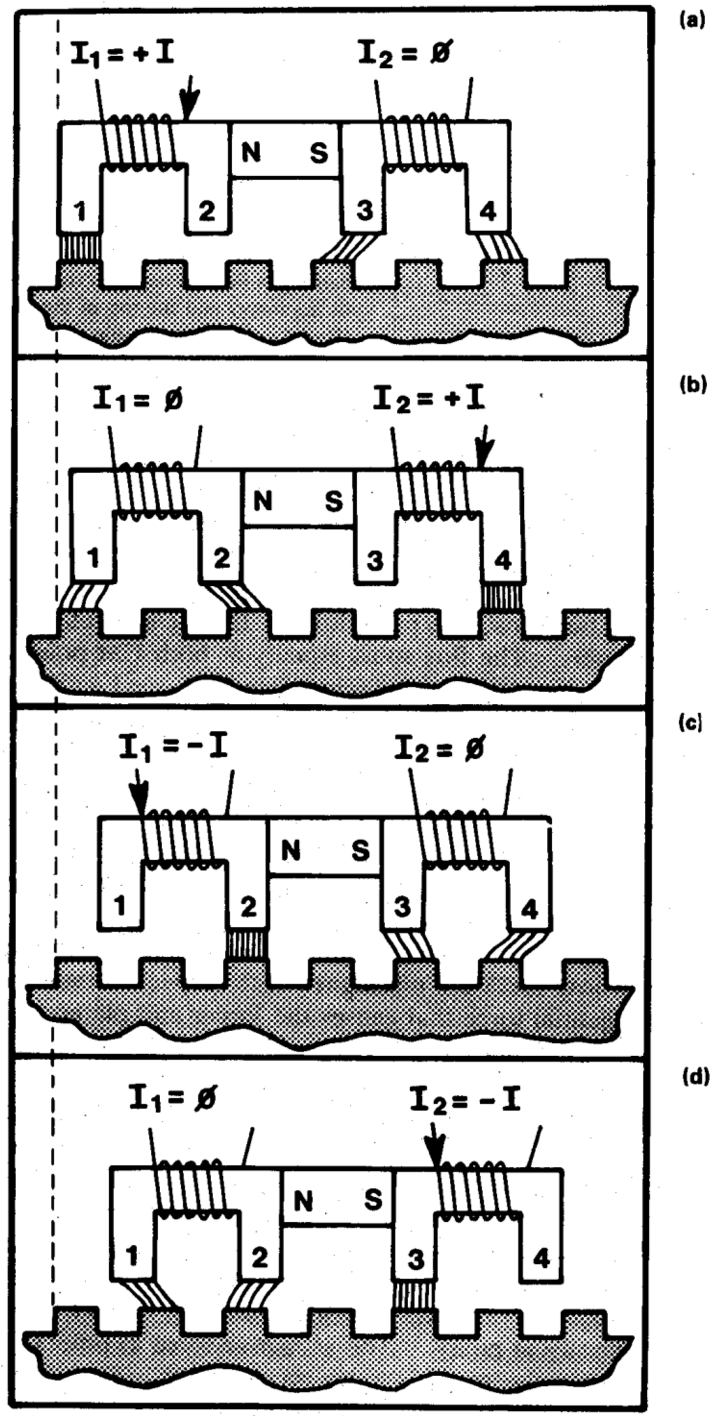
Working of a stepper motor

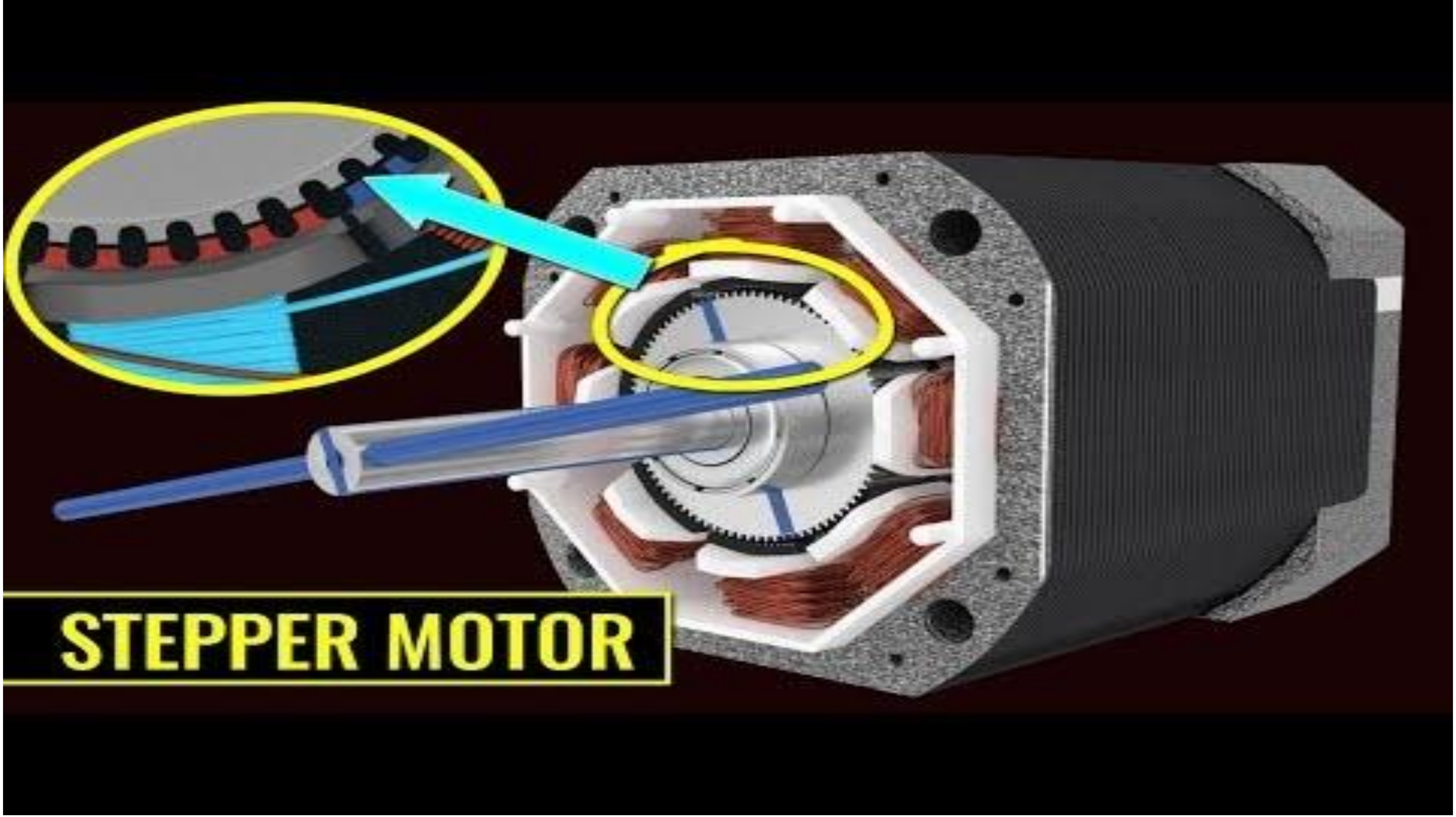
- **Sequence of rotation (CW): B – C – D - A’**



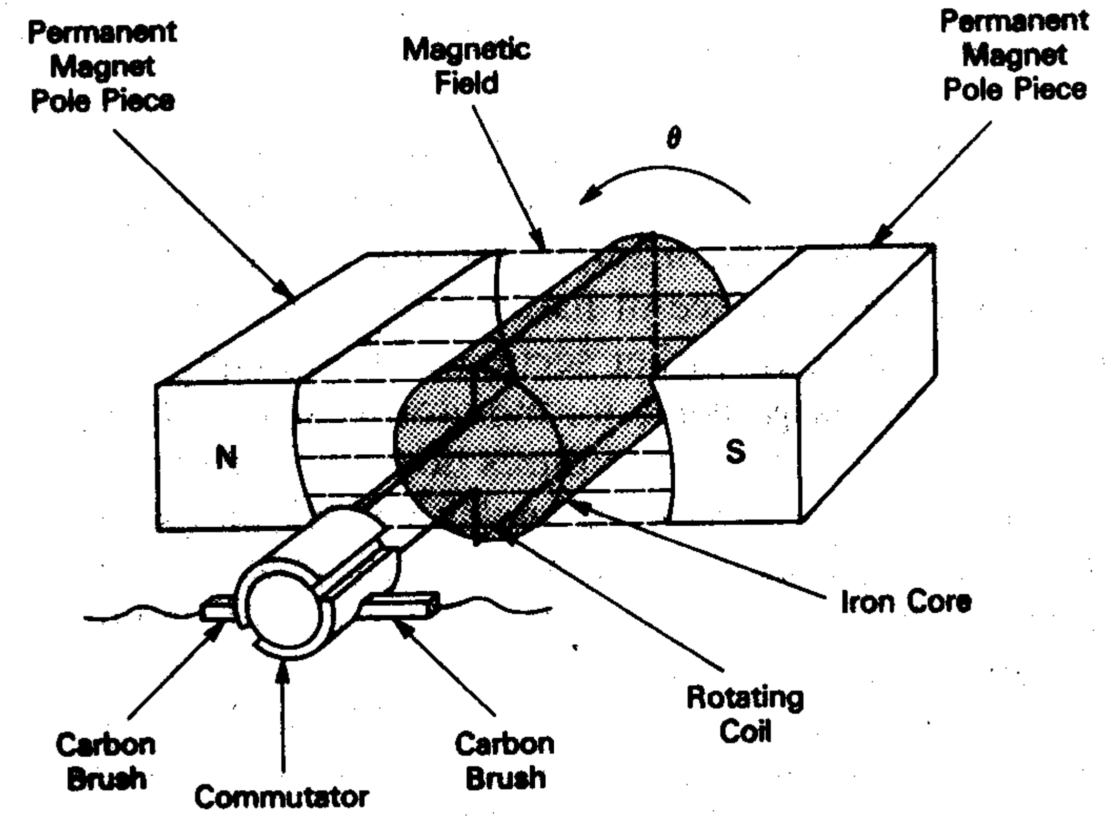
Linear stepper motors

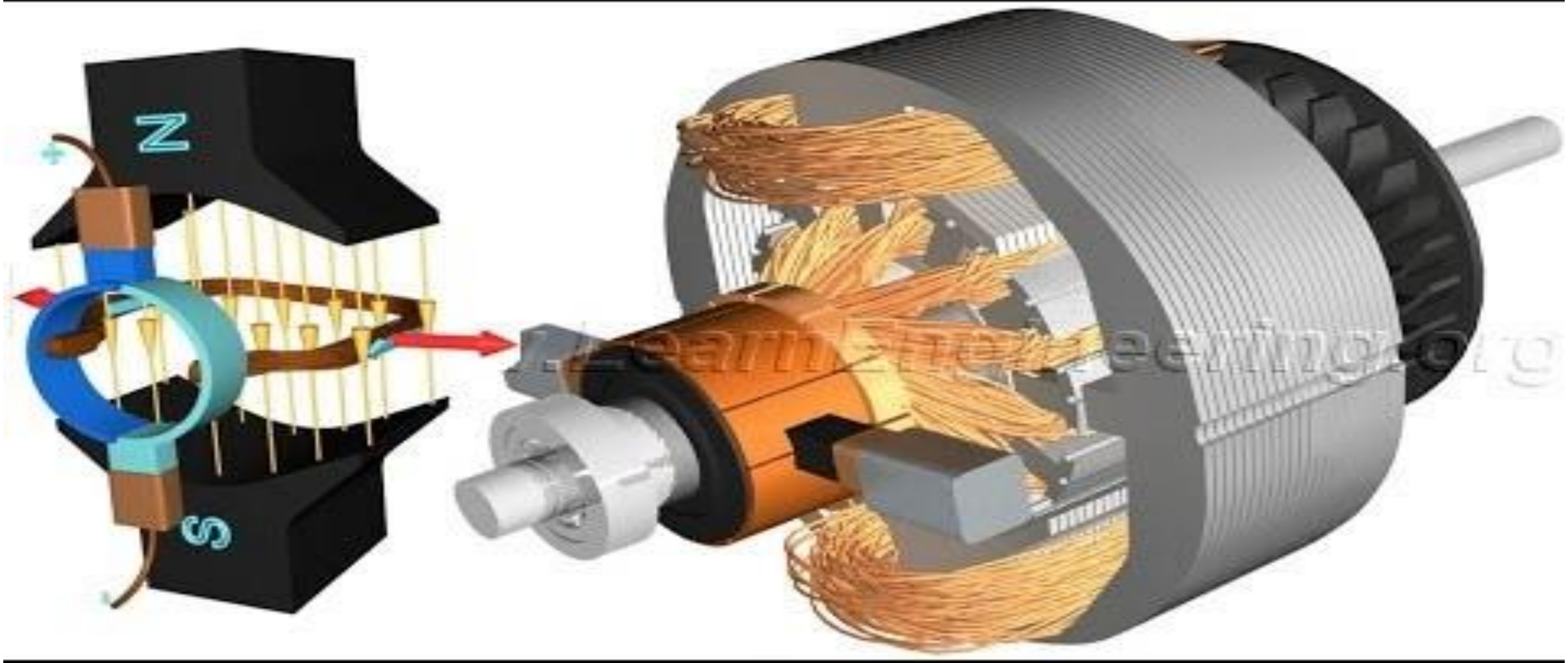





STEPPER MOTOR

DC Motors : basic working

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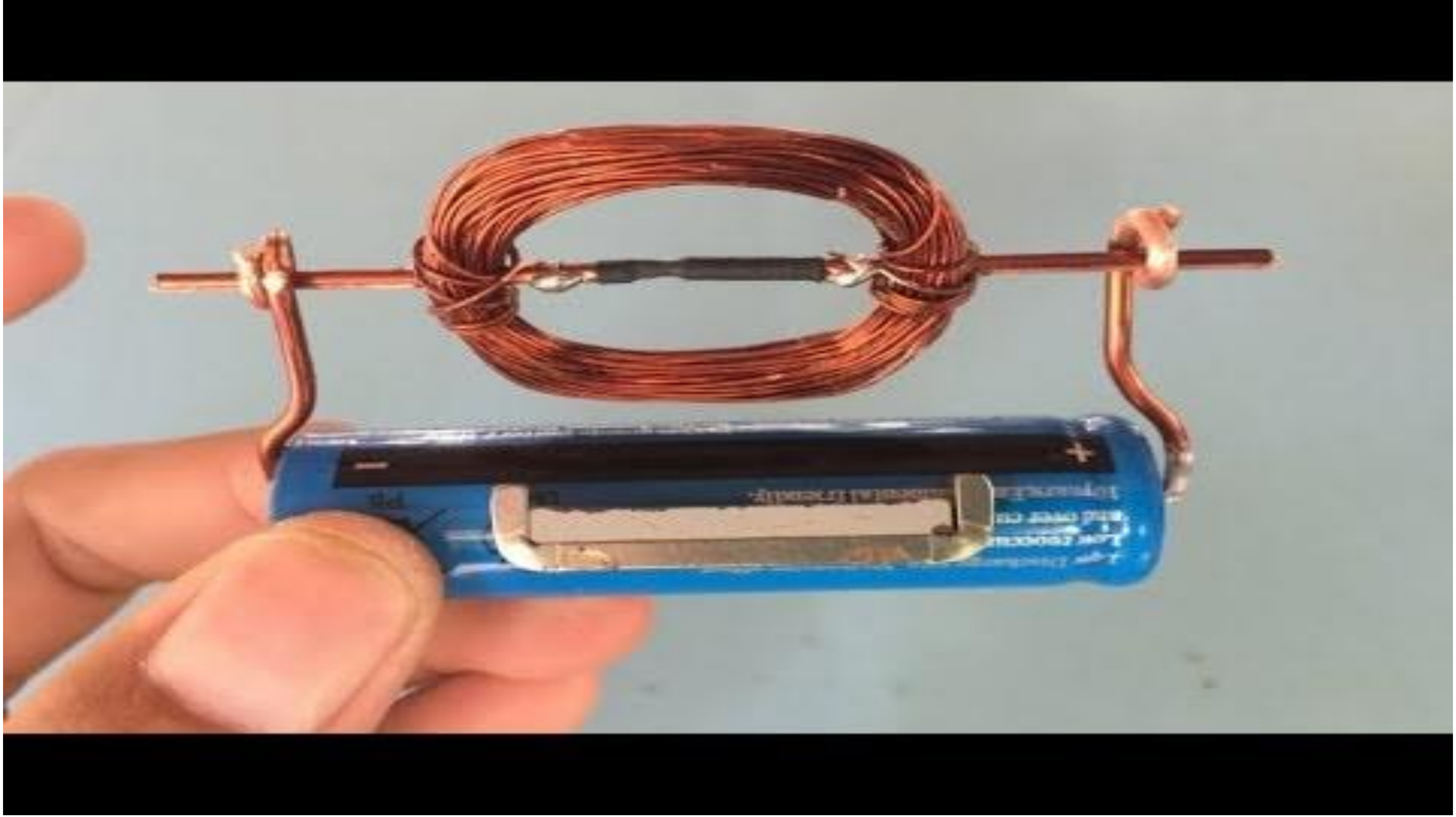

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Brushless DC motors

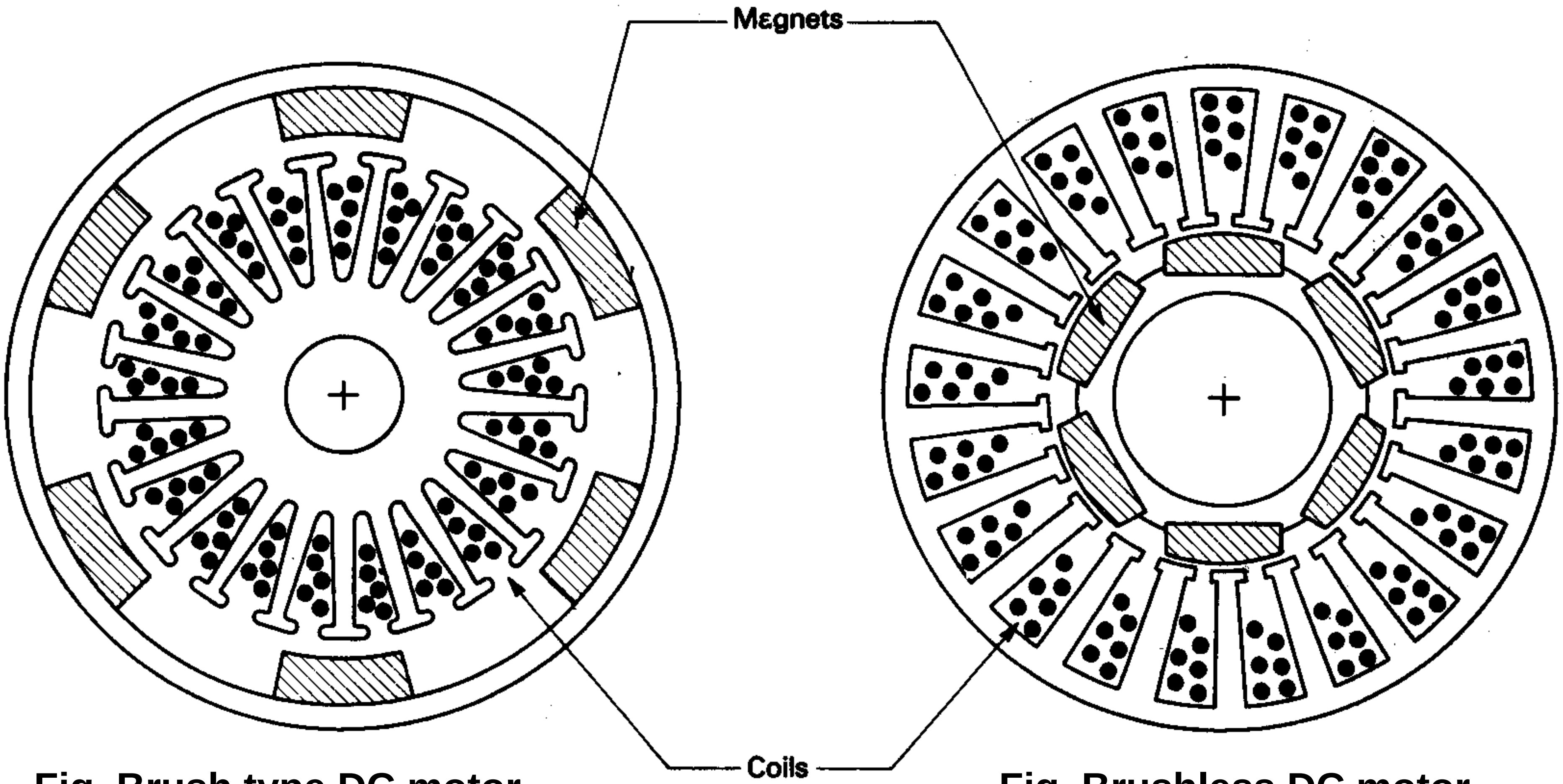
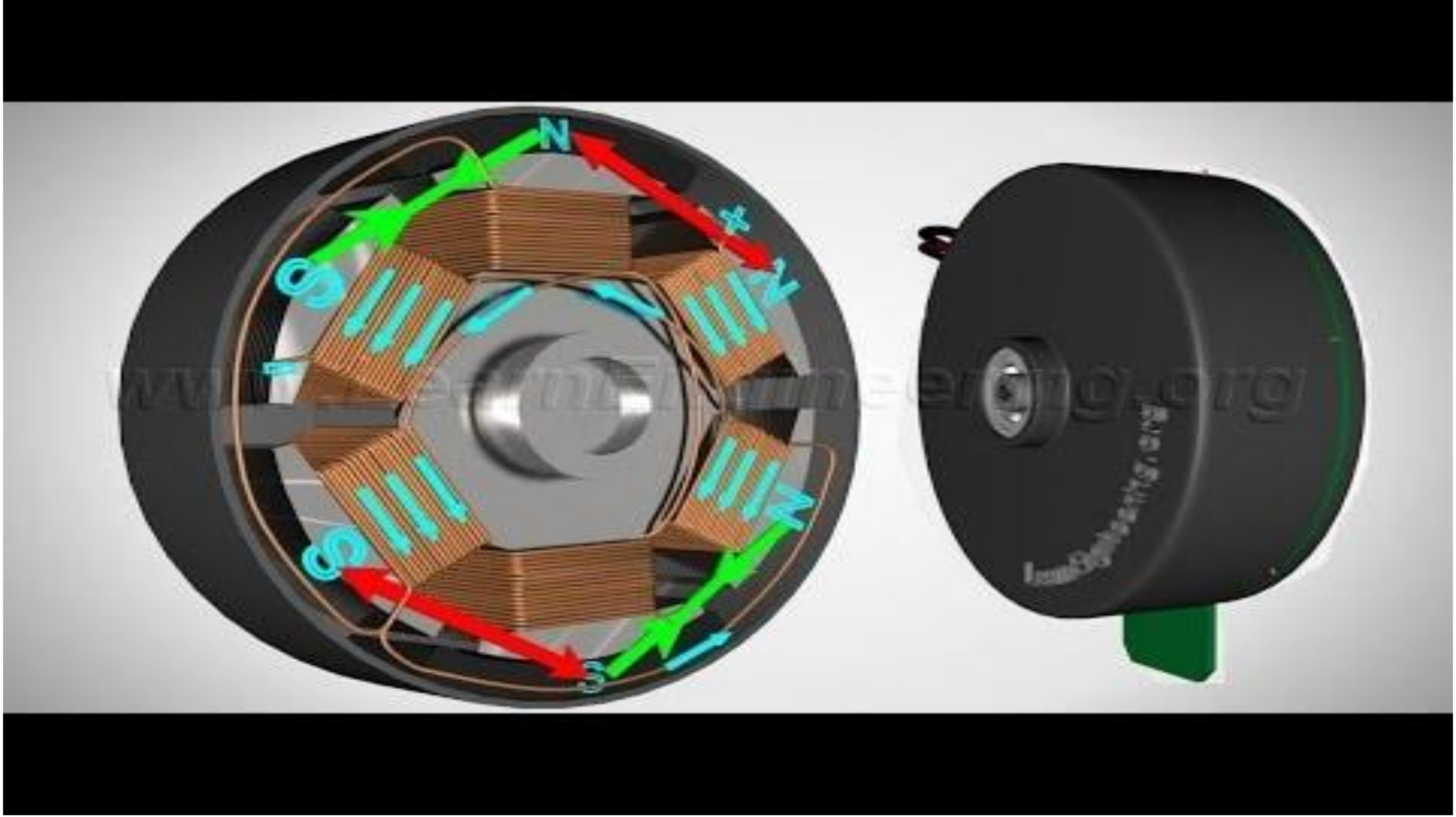


Fig. Brush type DC motor

Fig. Brushless DC motor



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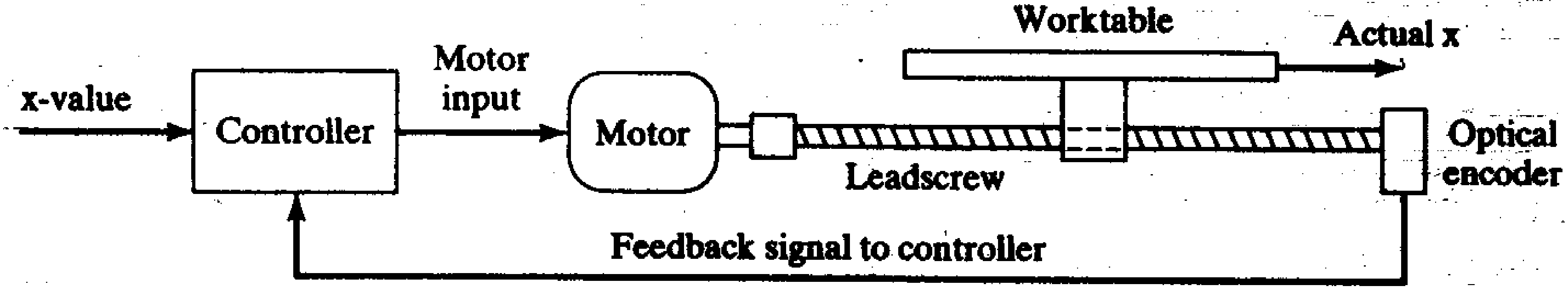
DC servo motors

- DC motors working in closed loop position control.

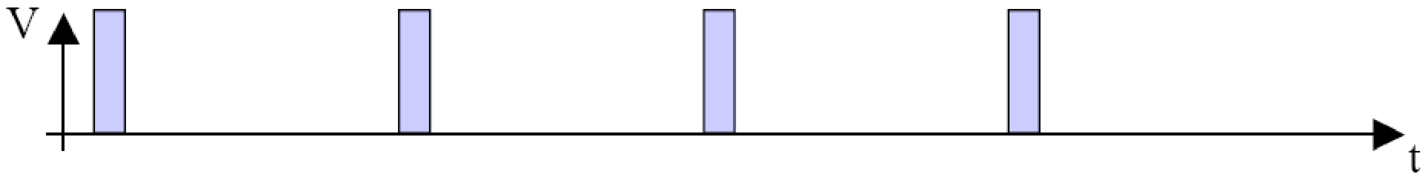


Servos

Photos: HiTec

- A servo is a unit combining motor and simple feedback electronics for position control
- A servo is set by supplying a PWM signal of a certain ratio
- Ratio determines servo position, not speed!
- Servos are usually used in model airplanes, etc.

Servos



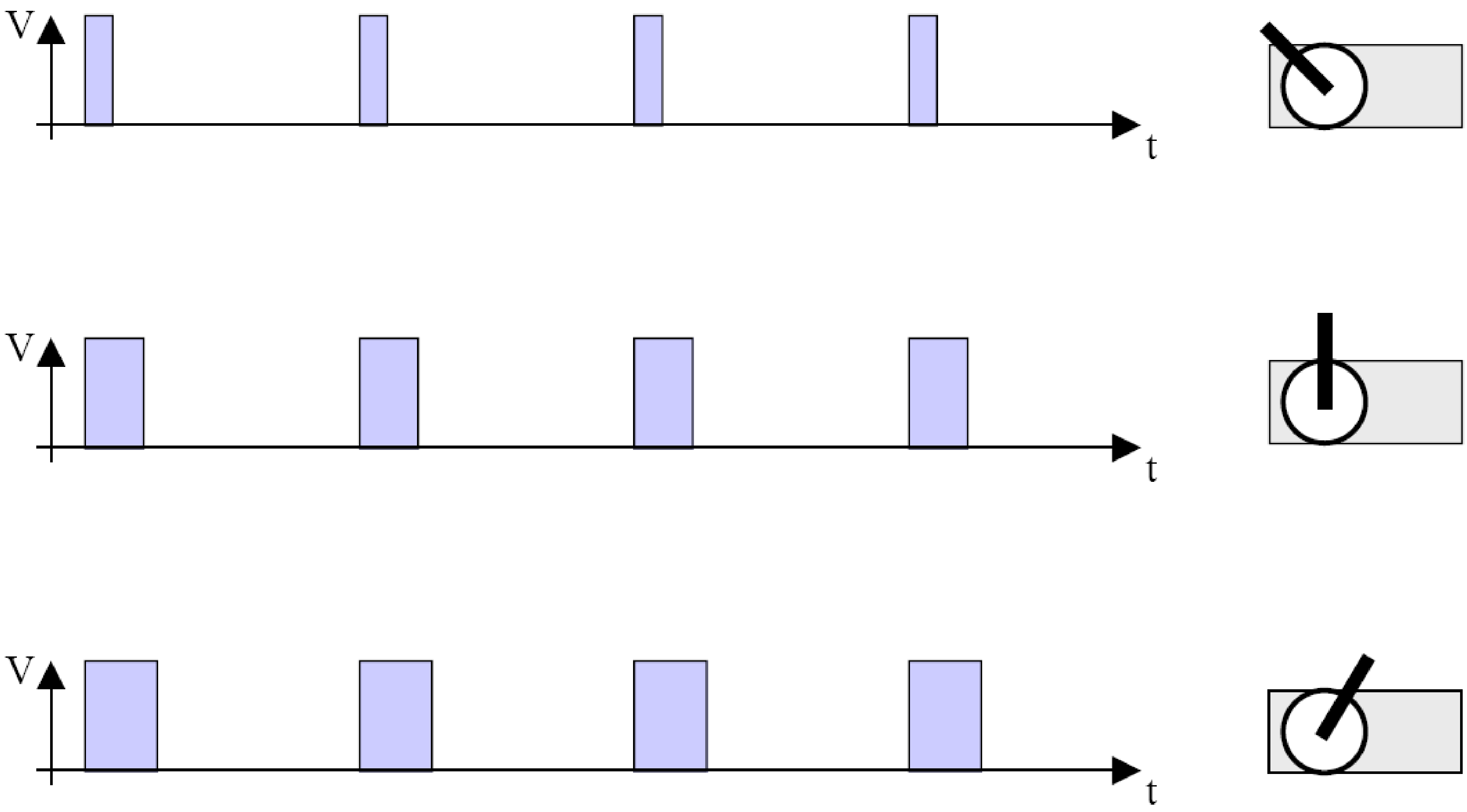
- Servos usually have three cables: power, ground and PWM-signal
- Servos require a PWM signal with 50Hz frequency (20ms)
- The pulse should be between 0.5 ms and 2.0 ms long
  this sets the servo to its extreme left or right position

Remember:

- Servo speed cannot be set
  servo tries to get to new position as fast as possible
- Servos do not provide feedback to the outside

•

Servos



Servos

- Terminology:
- Do not confuse “servos” with “servo motors”
- DC motors (brushed or brushless) are also sometimes also referred to as “servo motors”
  - See: http://www.theproductfinder.com/motors/bruser.htm

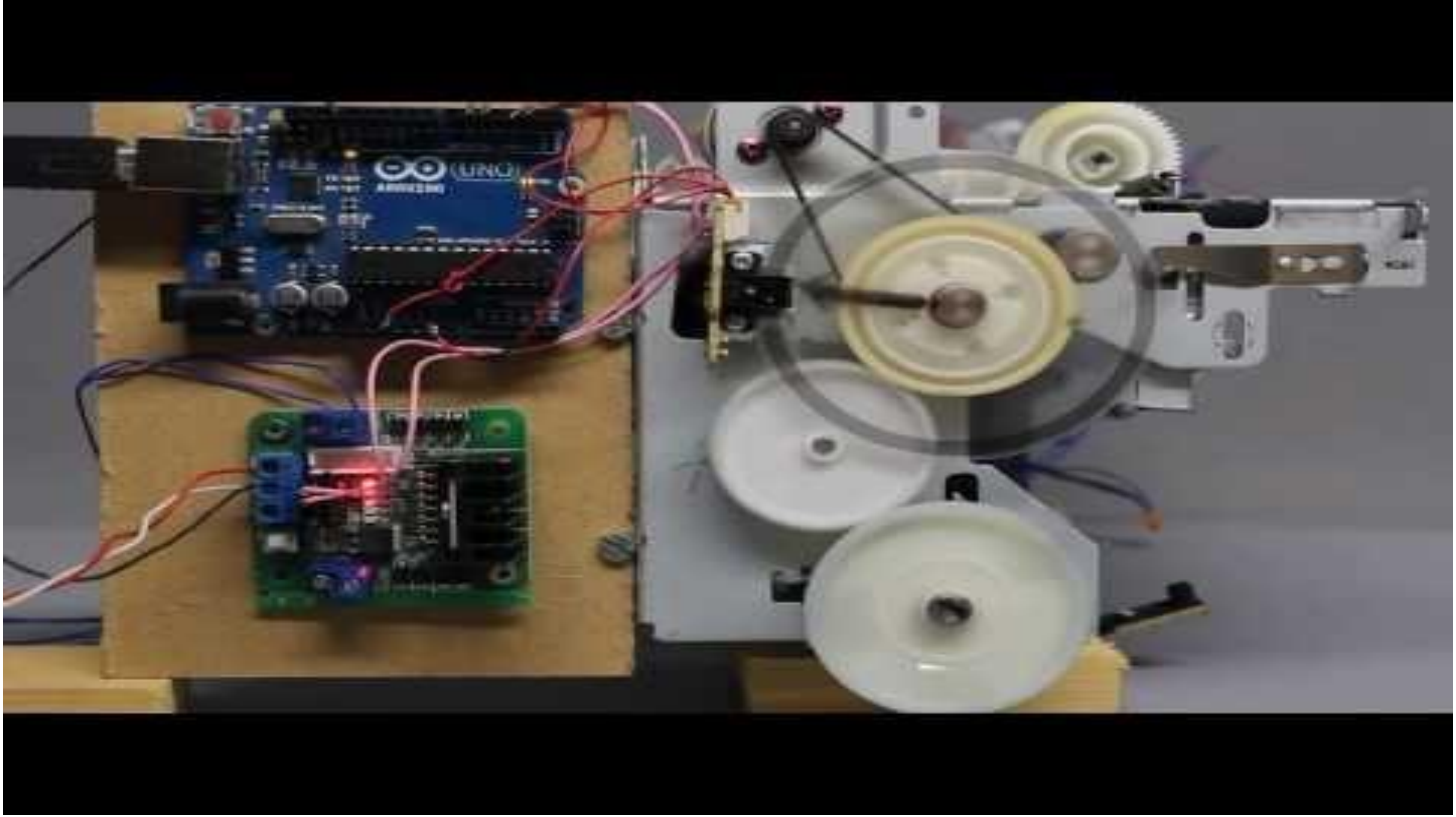
- “So when does a motor become a servo motor? There are certain design criteria that are desired when building a servo motor, which enable the motor to more adequately handle the demands placed on a closed loop system.

- First of all, servo systems need to rapidly respond to changes in speed and position, which require high acceleration and deceleration rates.

- This calls for extremely high intermittent torque.

Servos

- As you may know, torque is related to current in the brushed servo motor.
- So the designers need to keep in mind the ability of the motor to handle short bursts of very high current, which can be many times greater than the continuous current requirements.
- Another key characteristic of the brushed servo motor is a high torque to inertia ratio.
- This ratio is an important factor in determining motor responsiveness.
- Further, servo motors need to respond to small changes in the control signal.
- So the design requires reaction to small voltage variations."



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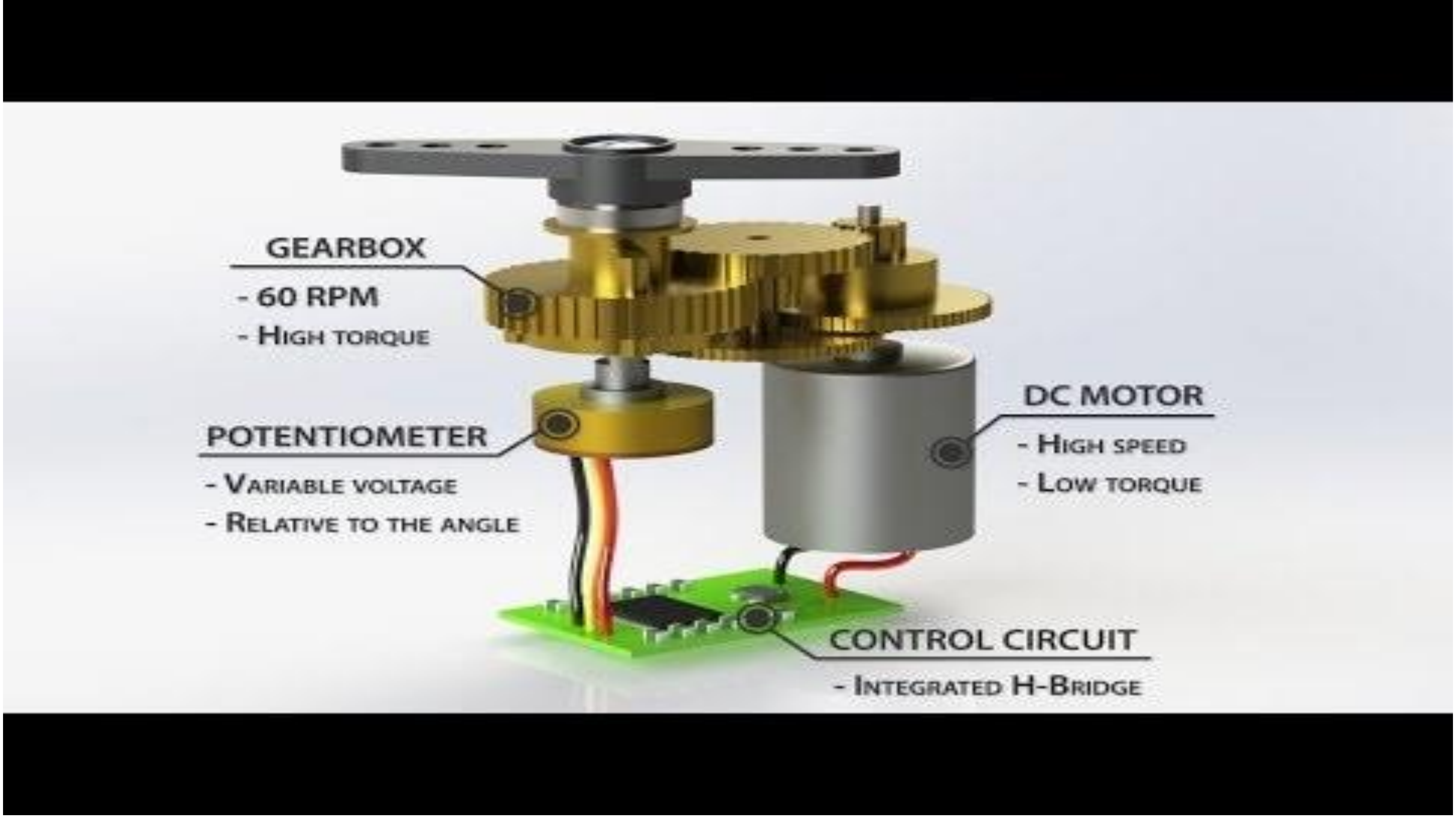
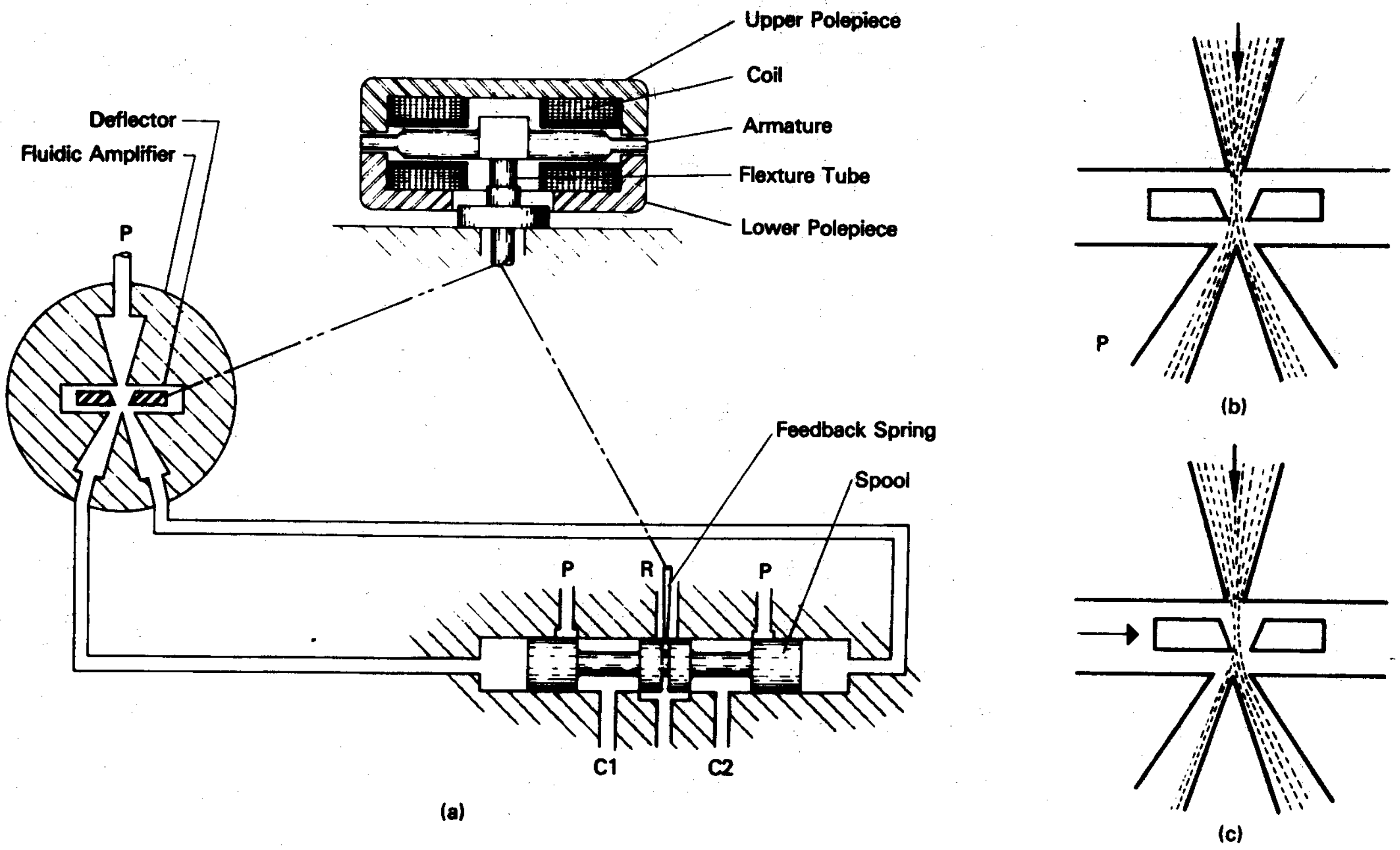
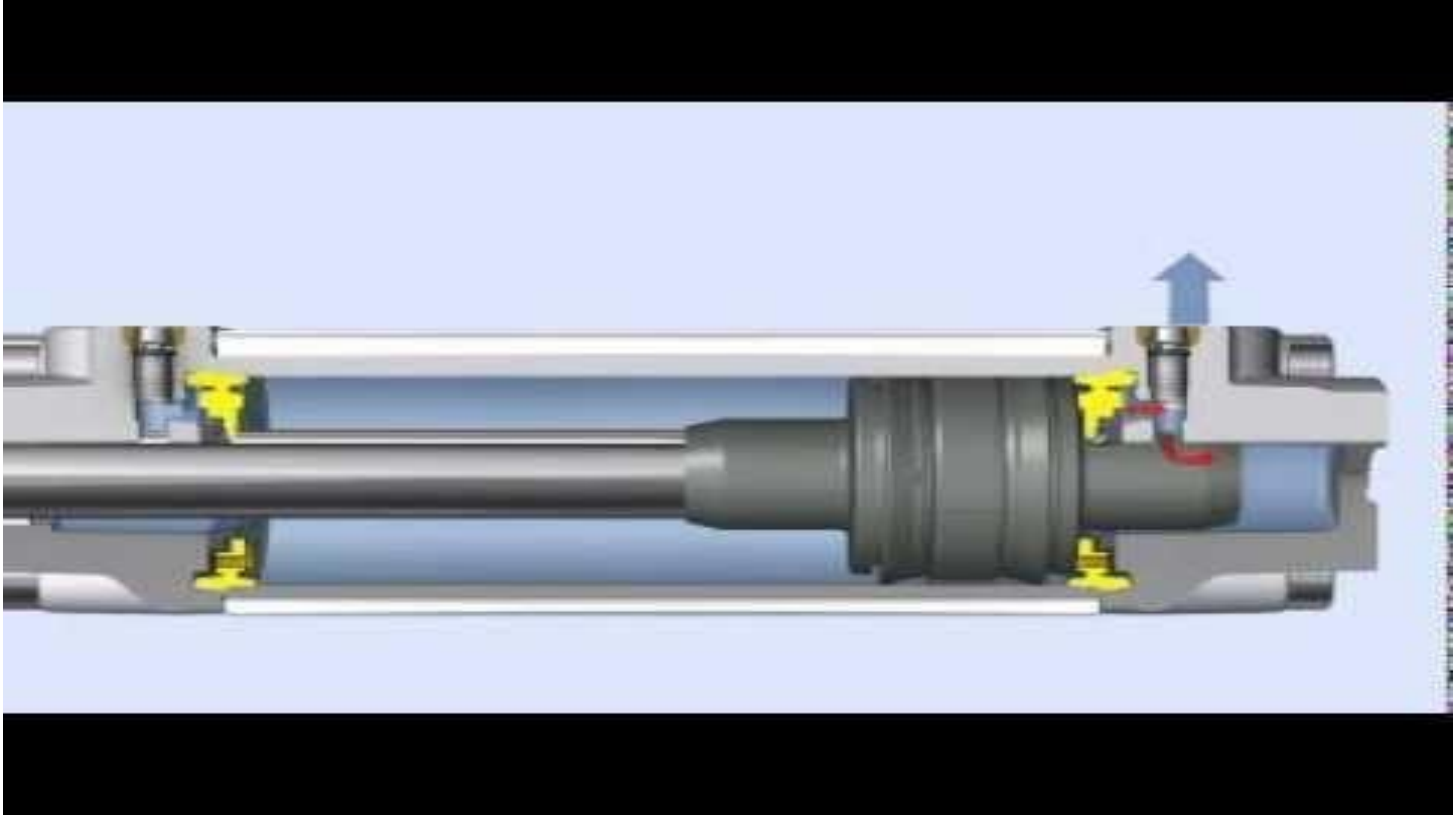
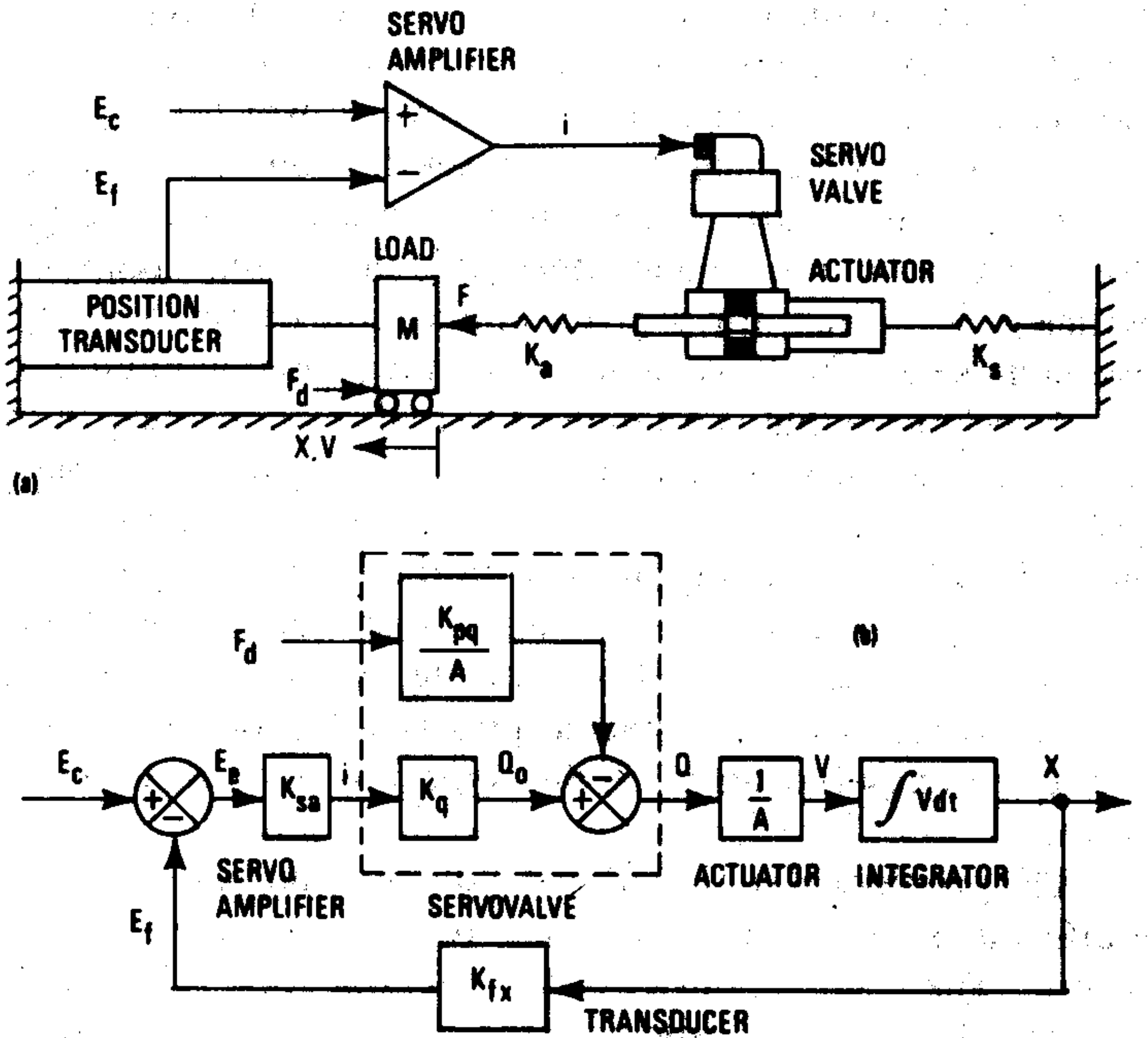

GEARBOX
- 60 RPM
- High torque
POTENTIOMETER
- Variable voltage
- Relative to the angle
DC MOTOR
- High speed
- Low torque
CONTROL CIRCUIT
- Integrated H-Bridge

Pneumatic actuators

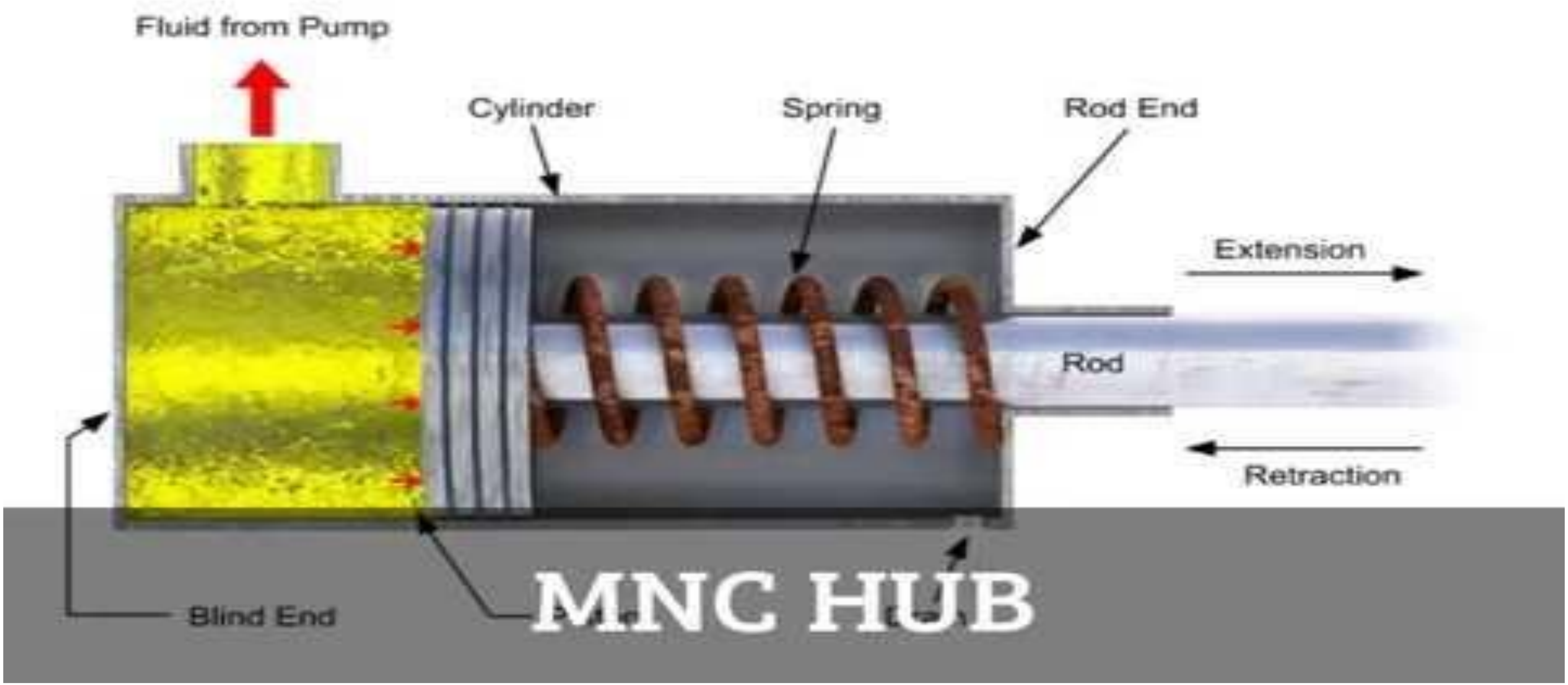




Hydraulic actuators: piston cylinder mechanism



Single Acting, Single ended Cylinder



Advanced actuators: small, low power consumption, micro motion

- **Ultrasonic motors : micro robots, cameras, micro motion devices ..**
  - **Motion due to dry friction and vibration.**
- **Artificial muscles : prosthetic, bio applications..**
- **Molecular motors : bio applications**
  - **Protein-based molecular motors harness the chemical free energy released by the hydrolysis of ATP in order to perform mechanical work.**