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NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE

(Accredited by NAAC, Approved by AICTE New Delhi, Affiliated to APJKTU)

Pampady, Thiruvilwamala(PO), Thrissur(DT), Kerala 680 588

DEPARTMENT OF MECHATRONICS

COURSE MATERIALS

MRT 281 INTRODUCTION TO SENSORS AND ACTUATORS

VISION OF THE INSTITUTION
To mould true citizens who are millennium leaders and catalysts of change through excellence in education.
MISSION OF THE INSTITUTION
NCERC is committed to transform itself into a center of excellence in Learning and Research in Engineering and Frontier Technology and to impart quality education to mould technically competent citizens with moral integrity, social commitment and ethical values. We intend to facilitate our students to assimilate the latest technological know-how and to imbibe discipline, culture and spiritually, and to mould them in to technological giants, dedicated research scientists and intellectual leaders of the country who can spread the beams of light and happiness among the poor and the underprivileged.

ABOUT DEPARTMENT

- Established in: 2013
- Course offered: B.Tech Mechatronics Engineering
- Approved by AICTE New Delhi and Accredited by NAAC
- Affiliated to the University of A P J Abdul Kalam Technological University.

DEPARTMENT VISION

To develop professionally ethical and socially responsible Mechatronics engineers to serve the humanity through quality professional education.

DEPARTMENT MISSION

1) The department is committed to impart the right blend of knowledge and quality education to create professionally ethical and socially responsible graduates.
2) The department is committed to impart the awareness to meet the current challenges in technology.
3) Establish state-of-the-art laboratories to promote practical knowledge of mechatronics to meet the needs of the society

PROGRAMME EDUCATIONAL OBJECTIVES

I. Graduates shall have the ability to work in multidisciplinary environment with good professional and commitment.
II. Graduates shall have the ability to solve the complex engineering problems by applying electrical, mechanical, electronics and computer knowledge and engage in lifelong learning in their profession.
III. Graduates shall have the ability to lead and contribute in a team with entrepreneur skills, professional, social and ethical responsibilities.
IV. Graduates shall have ability to acquire scientific and engineering fundamentals necessary for higher studies and research.

PROGRAM OUTCOME (PO'S)

Engineering Graduates will be able to:

PO 1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO 2. Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO 3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO 4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO 5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO 6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO 7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO 8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO 9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO 10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO 11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO 12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOME (PSO'S)

PSO 1: Design and develop Mechatronics systems to solve the complex engineering problem by integrating electronics, mechanical and control systems.

PSO 2: Apply the engineering knowledge to conduct investigations of complex engineering problem related to instrumentation, control, automation, robotics and provide solutions.

MRT 281	INTRODUCTION TO SENSORS AND ACTUATORS	CATEGORY	L	T	P	CREDIT
		VAC	4	0	0	4

Preamble:

Sensors and actuators play a vital role in manufacturing, machinery, aerospace, medicine and robotics. Most of the advancements of present day would be not possible without sensors. The main purpose of offering this course is to elaborate the theoretical and practical aspects of sensors and actuators, their classifications, recent trends and their applications in day to day life.

Prerequisite: Nil

Course Outcomes: After the completion of the course the student will be able to

CO 1	Get an exposure to sensors and actuators and its importance in the real world.
CO 2	Explain the working of magnetic sensors and its applications in real time scenario
CO 3	Model linear actuators and differentiate various solenoids
CO 4	Explain the working principle of different types of rotary actuators
CO 5	Understand the basic idea on the controls in NC machine and fluidic system.

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	**3**	2	2						2			
CO2	**3**	2	2						2			
CO3	**3**	2	2						2			
CO4	**3**	2	2						2			
CO5	**3**	2	2						2			

Assessment Pattern

Bloom's Category	Continuous Assessment Tests		End Semester Examination
	1	2	
Remember	10	10	10
Understand	20	20	20
Apply	20	20	70
Analyse			
Evaluate			
Create			

Mark distribution

Total Marks	CIE	ESE	ESE Duration
150	50	100	3 hours

Continuous Internal Evaluation Pattern:

Attendance : 10 marks
Continuous Assessment Test (2 numbers) : 25 marks
Assignment/Quiz/Course project : 15 marks

End Semester Examination Pattern: There will be two parts; Part A and Part B. Part A contain 10 questions with 2 questions from each module, having 3 marks for each question. Students should answer all questions. Part B contains 2 questions from each module of which student should answer any one. Each question can have maximum 2 sub-divisions and carry 14 marks.

QUESTION BANK

MODULE I				
Q:NO:	**QUESTIONS**	**CO**	**KL**	**PAGE NO:**
1	Define the term Actuators. Explain in details.	CO1	K2	
2	Elaborate on latching solenoid actuators.	CO1	K2	
3	List out the types of stepper motor and write the working principle of a stepper motor also explain the working of variable reluctance SM.	CO1	K1	
4	State the difference between Rotary and linear Actuators with neat sketch.	CO1	K3	
5	Write a short note about soft magnetic material.	CO1	K2	
6	What are magnetic materials? Describe a brief note on magnetic materials and its technology.	CO1	K1	
7	State Faraday's law of electromagnetic induction. Also explain the various challenges faced, while designing a special magnetic device.	CO1	K3	
8	What are the types of electrical Actuators? Explain in details.	CO1	K2	
9	Explain the various challenges faced, while designing a special magnetic device?	CO1	K2	
10	Explain about hard magnetic materials with examples.	CO1	K2	
11	State the difference between Rotary and linear Actuators with neat sketch.	CO1	K3	

MODULE II				
1	Explain the role of magnetic sensors as a position sensor	CO2	K2	
2	Analysis the various methods implemented to reduce VR sensor noise.	CO2	K4	
3	Give a short note, about the applications and requirement of magnetic sensors?	CO2	K2	
4	Explain the role of magnetic sensors as a position sensor.	CO2	K2	
5	Explain magnetic speed sensor application.	CO2	K2	
6	Describe different applications of VR sensor.	CO2	K3	
7	Explain magnetic sensor in detail and identify some of its applications.	CO2	K2	
8	Explain about VR sensors with suitable sketches.	CO2	K2	
9	Explain about various types of magnetic sensors.	CO2	K2	
10	Write a short note about the drawbacks of each magnetic sensor types.	CO2	K2	
11	Illustrate the application of a magnetic sensor in speed sensing requirements	CO2	K2	
MODULE III				
1	Illustrate the difference between ball solenoid and conical solenoid, with the help of neat drawing.	CO3	K2	
2	Explain the basic working principle and	CO3	K2	

	construction details of a solenoid valve with a neat diagram.			
3	Elaborate on plunger solenoid with the help of neat diagram.	CO3	K2	
4	Explain the construction and working details of conical solenoid with neat drawing.	CO3	K2	
5	Illustrate the working of Disk solenoid?	CO3	K2	
6	Illustrate the working of Plunger solenoid?	CO3	K2	
7	Analysis the various advantages of fuel injection over conventional fuel pump.	CO3	K4	
8	What is the difference between gasoline injectors and natural gas injectors?	CO3	K3	
9	Illustrate the working principle of long stock solenoid fuel pump.	CO3	K2	
10	Write a short note about applications of solenoid actuators.	CO3	K1	
11	Write a short note on injector? Explain about diesel fuel injectors.	CO3	K1	
12	Explain the working of solenoids also explain the conventional hydraulic valve body for a hydraulic transmission.	CO3	K2	
13	What are the types of solenoid fuel pumps? Explain any one in details.	CO3	K2	
14	Define the term solenoids. Also explain solenoid actuators.	CO3	K1	
15	Write about long stroke solenoid fuel pump.	CO3	K1	
16	Explain the working of compressor	CO3	K2	

	solenoid valves with the help of neat diagram.			
17	Explain transmission solenoids with the help of neat diagram	CO3	K2	
MODULE IV				
1	Explain disk rotary actuators with position arrangement.	CO4	K2	
2	Write about disk rotary actuators design.	CO4	K1	
3	Explain the term rotary actuators.	CO4	K2	
4	Write about disk rotary actuator test and explain the geometry of rotary actuator.	CO4	K1	
5	Explain Cylindrical Rotary Actuators with neat sketches.	CO4	K2	
6	Identify the various applications of Cylindrical Rotary Actuator and Disk Rotary Actuators in	CO4	K3	
7	Write about the application of disk rotary actuators.	CO4	K2	
8	Draw and explain claw pole actuator toothed magnet.	CO4	K2	
9	Explain about claw pole actuator PM	CO4	K2	
10	Explain the applications of cylindrical rotary actuators.	CO4	K2	
MODULE V				
1	Write a short note, about the feedback devices used in closed loop system.	CO5	K1	
2	Enumerate the role of hydraulic actuators in the drives used for NC.	CO5	K2	
3	Discuss the difference between closed loop and opened loop control system with the help of neat sketch.	CO5	K3	

4	Explain the basic working principle of fluidic logic control.	CO5	K2	
5	Explain the term Numerical Control.	CO5	K2	
6	Describe different between open and closed loop control system.	CO5	K3	
7	Elaborate on drives for NC and Robotic Systems.	CO5	K2	

APPENDIX 1

CONTENT BEYOND THE SYLLABUS

S:NO;	TOPIC	PAGE NO:
1	Automotive components.	
2	Adaptive cruise control.	

MODULE 1

COURSE CODE:MRT 204

SENSORS AND ACTUATORS

PRESENTED BY
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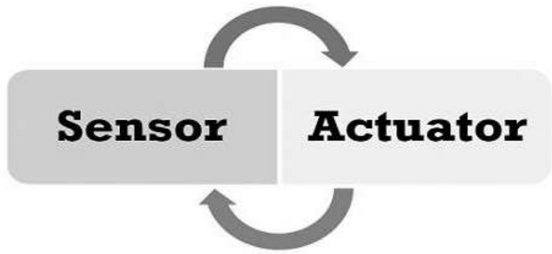
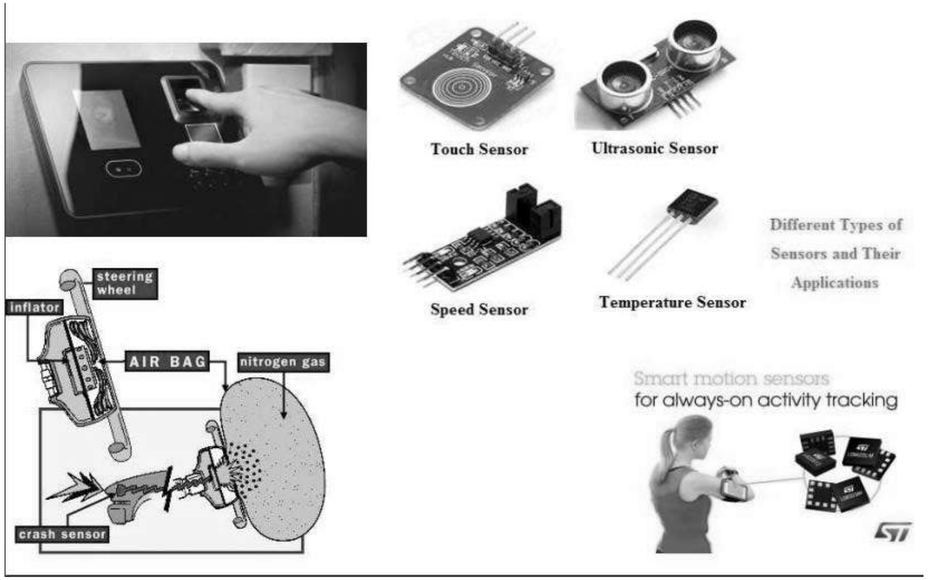


- Sensors and Actuators are essential elements of the embedded systems.
- These are used in several real-life applications such as.....
  - flight control system in an aircraft
  - process control systems in nuclear reactors
  - power plants that require to be operated on an automated control.

SENSOR

- A sensor is an electronic instrument that is able to measure the physical quantity and generate a considerate output.
- These output of the sensors are usually in the form of electrical signals.
- A device that responds to a physical stimulus (as heat, light, sound, pressure, magnetism, or a particular motion) and transmits a resulting impulse (as for measurement or operating a control) . (Webster, 3rd ed., 1999
- In conclusion: A device that responds to a physical stimulus.



- There are various types of sensors such as position, temperature, pressure, speed sensors, but fundamentally there are two types – analog and digital.
- The different types come under these two basic types. A digital sensor is incorporated with an Analog-to-digital converter while analog sensor does not have any ADC.
- Sensors are omnipresent. They embedded in our bodies, automobiles, airplanes, cellular telephones, radios, chemical plants, industrial plants and countless other applications.
- Without the use of sensors, there would be no automation !!

Other Sensors

- Temperature
- RFID
- Barcode
- Proximity
- Vision
- Gyroscope
- Compass
- Tilt/Acceleration

Transducers

- a device that converts a primary form of energy into a corresponding signal with a different energy form
- Primary Energy Forms: mechanical, thermal, electromagnetic, optical, chemical, etc.
- A substance or device, such as a piezoelectric crystal, that converts input energy of one form into output energy of another. (from: Trans-ducere – to transfer, to lead) (American Heritage Dictionary, 3rd ed., 1996)

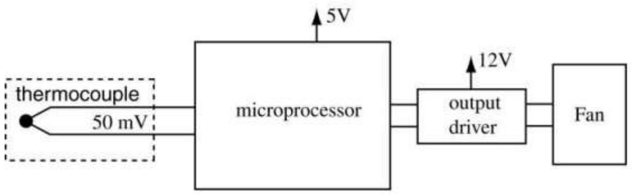
Actuators

- One that actuates; a mechanical device for moving or controlling something. (Webster, 3rd ed., 1999)
- Hardware devices that convert a controller command signal into a change in a physical parameter
- The change is usually mechanical (e.g., position or velocity)
- An actuator is also a transducer because it changes one type of physical quantity into some alternative form
- An actuator is usually activated by a low-level command signal, so an amplifier may be required to provide sufficient power to drive the actuator

- An actuator is a device that alters the physical quantity as it can cause a mechanical component to move after getting some input from the sensor.
- In other words, it receives control input (generally in the form of the electrical signal) and generates a change in the physical system through producing force, heat, motion, etcetera.
- For example: the stepper motor

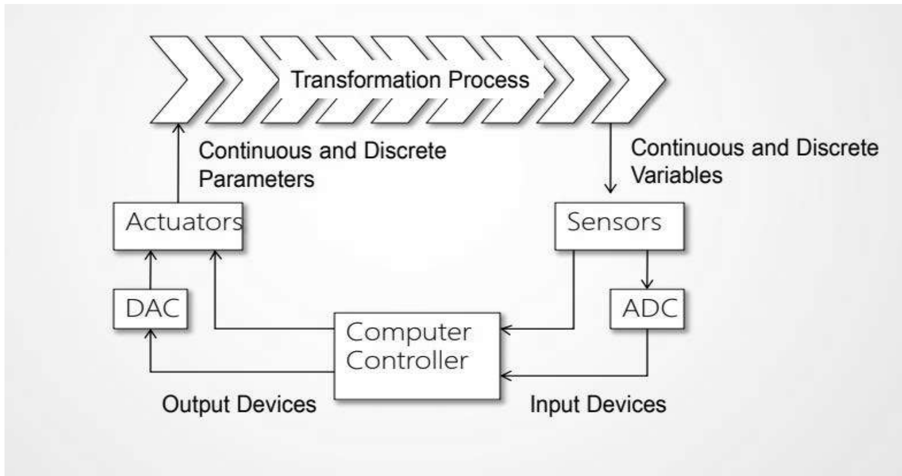
- where an electrical pulse drives the motor. Each time a pulse given in the input accordingly motor rotates in a predefined amount.
- A stepper motor is suitable for the applications where the position of the object has to be controlled precisely, for example, robotic arm.

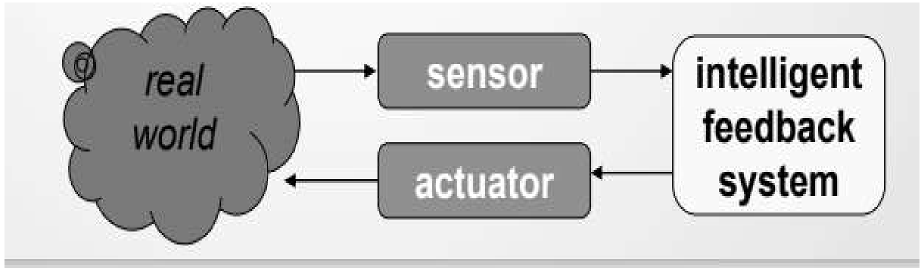
Example - Temperature control



- Sense the temperature of a CPU
- Control the speed of the fan to keep the temperature constant

Computer Process Control System





Key Differences Between Sensors and Actuators

- A sensor is a device that changes a physical parameter to an electrical output. As against, an actuator is a device that converts an electrical signal to a physical output.
- The sensor is situated at the input port to take the input, whereas an actuator is placed at the output port.
- Sensor generates electrical signals while an actuator results in the production of energy in the form of heat or motion.

CLASSIFICATION OF SENSORS AND ACTUATORS

1. Active and passive sensors

- **Active sensor**: a sensor that requires external power to operate. Examples: the carbon microphone, thermistors, strain gauges, capacitive and inductive sensors, etc.
- Other name: parametric sensors (output is a function of a parameter - like resistance)
- **Passive sensor**: generates its own electric signal and does not require a power source. Examples: thermocouples, magnetic microphones, piezoelectric sensors.
- Other name: self-generating sensors

2. Contact and noncontact sensors

- **Contact sensor:** a sensor that requires physical contact with the stimulus. Examples: strain gauges, most temperature sensors
- **Non-contact sensor:** requires no physical contact. Examples: most optical and magnetic sensors, infrared thermometers, etc.

3. Absolute and relative sensors

- **Absolute sensor:** a sensor that reacts to a stimulus on an absolute scale: Thermistors, strain gauges, etc., (thermistor will always read the absolute temperature)
- **Relative scale:** The stimulus is sensed relative to a fixed or variable reference. Thermocouple measures the temperature difference, pressure is often measured relative to atmospheric pressure.

4. Analog and Digital Type

- **Analog**: Output varies continuously, infinite position for the pointer
- **Digital**: Output varies in discrete form. Finite number of positions

5.Other schemes

- Electric sensors
- Magnetic
- Electromagnetic
- Acoustic
- Chemical
- Optical
- Heat, Temperature
- Mechanical
- Radiation
- Biological

Types of Actuators

1. Electrical actuators
   - Electric motors
     - DC servomotors
     - AC motors
     - Stepper motors
   - Solenoids
2. Hydraulic actuators
   - Use hydraulic fluid to amplify the controller comm
3. Pneumatic actuators
   - Use compressed air as the driving force

What is Magnetic Sensor?

- The Sensors, transducers which uses the changes in magnetic field for their operations.
- Used to measure the currents, speed, position and Displacement.
- As the conventional sensors, Magnetic sensor does not give output parameters directly.
- Signal processing is required for desired output.

Difference between Conventional and Magnetic Sensors:

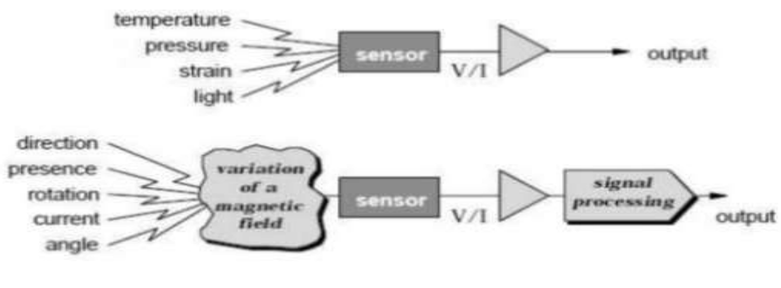


Figure 1. Conventional vs. Magnetic Sensing

Low Field Sensors:

Can sense very low values of magnetic fields, less then **1μG**

1 Gauss = 10^{-4} Tesla

For Example SQUID, Fiber-Optic , Nuclear Procession

Uses:

In medical and nuclear application.

Earth Field Sensor:

- The magnetic range for the medium field sensors lends 1µGauss to 10 Gauss
- Uses the Earth's magnetic field in many of applications for Example,

Navigation and Vehicle Detection

BIAS MAGNET FIELD SENSORS:

- Can Sense the large magnetic fields more then 10 Gauss.
- Most industrial sensors use permanent magnets as a source of the detected magnetic field.
- These permanent magnets magnetize, or bias, ferromagnetic objects close to the sensor.
- Sensors in this category include reed switches, Hall devices, and GMR sensors….

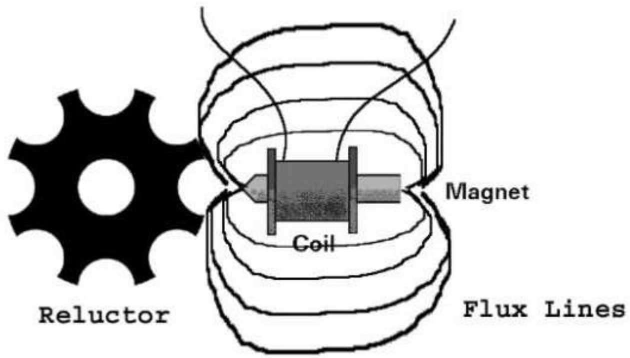
Variable Reluctance Sensors:

- These sensors often measure Rotation.
- They create their own A/C voltage.
- Senses speed and position of rotating objects.
- Have many applications as:

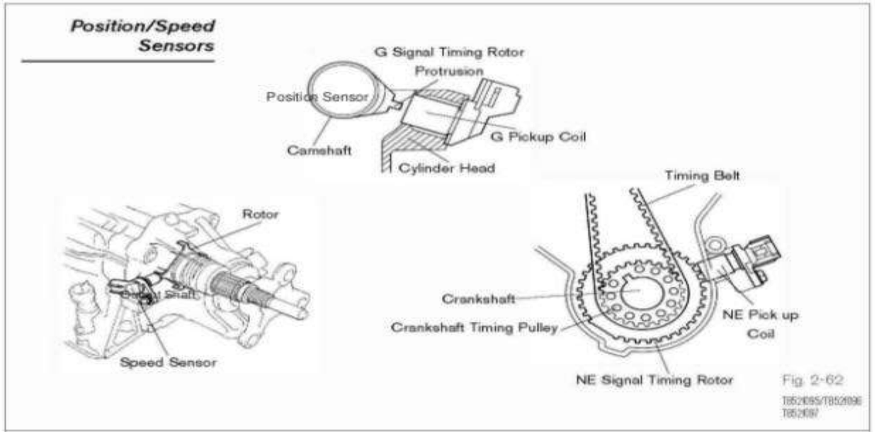
  i) Magnetic Pulse Generators.
  ii) Pickup Coils.
  iii) Reluctor Sensors.

Working:

- Consist of a permanent Magnet and a Fixed coil on it.
- As the ferromagnetic wheel having tooth rotates, It changes the flux in the coil and in result the AC voltage is induced
- The frequency of this voltage depends on the speed of wheel
- The Output of the sensor is measured digitally using Signal processing techniques



Applications:



Inductive Sensors:

- Translate movement into a change in the inductance between magnetically coupled parts.
- The inductance principle is also used in differential transformers to measure translational and rotational displacements.

For Example,

inductive displacement transducer ,LVDT.

Working:

- ✓ The single winding on the central limb of a **'E'-shaped** ferromagnetic body is excited with an alternating voltage.
- ✓ The displacement to be measured is applied to a ferromagnetic plate in close proximity to the 'E' piece as

$$\mathbf{I = V/\omega L.}$$

- ✓ For the fixed values of **V** and **ω** the relationship **I** and **L** can be used to find the displacement.

Inductive Displacement Sensor:

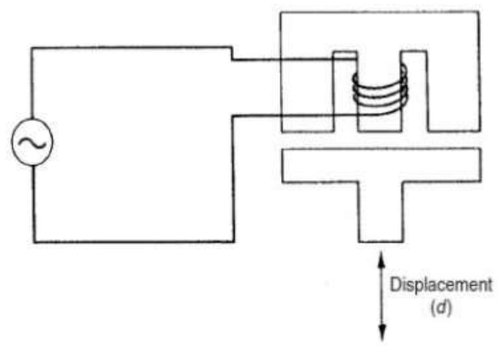


Fig. 13.1 Inductive displacement sensor.

MRT 281:INTRODUCTION TO SENSORS AND ACTUATORS

STEPPER MOTOR

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TYPE OF ELECTRICAL ACTUATORS

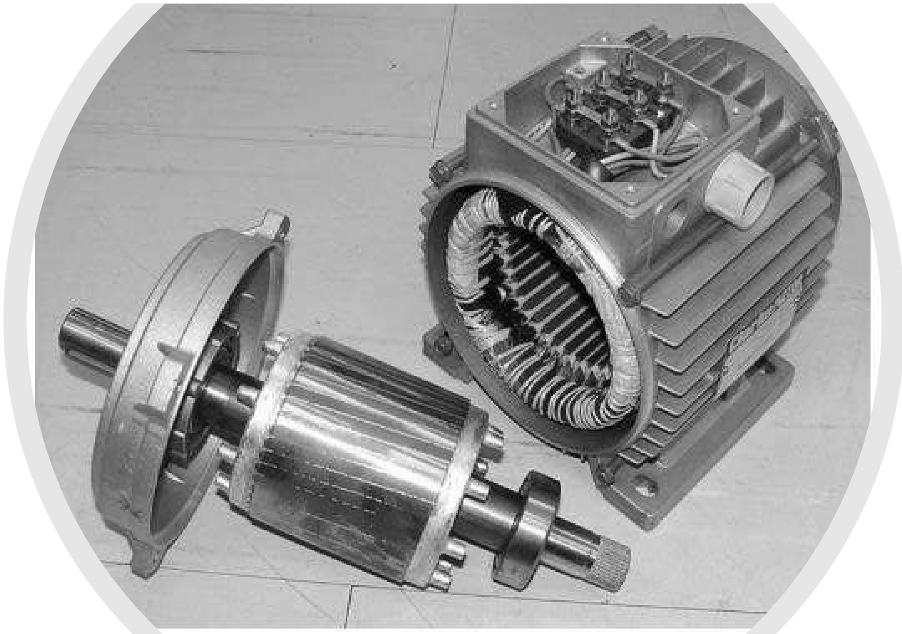
1.ELECTRICAL MOTOR

- DC SERVO MOTOR
- AC MOTOR
- STEPPER MOTOR

2.SOLENOIDS

AC MOTOR

- A machine which converts electrical energy into mechanical energy is called as motor
- Motor is divided into two types depend upon the supply
  - AC MOTOR
  - DC MOTOR



Ac motor is divided into three types they are:

- Three phase motors
  - induction motor
  - synchronous motor
- Single phase motors
- Special motors

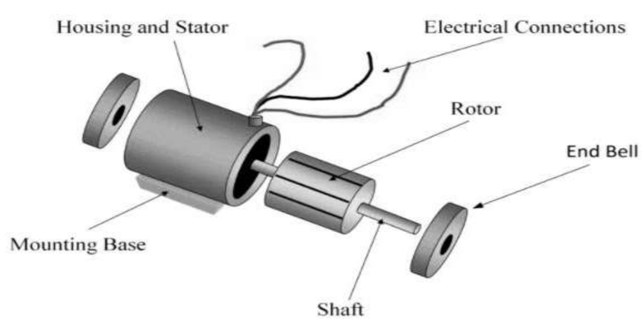
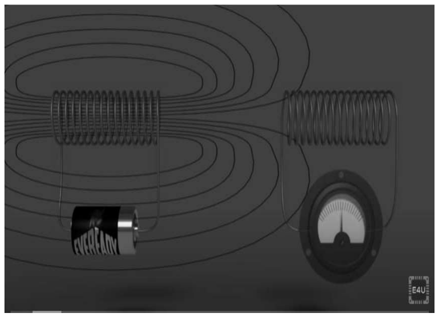


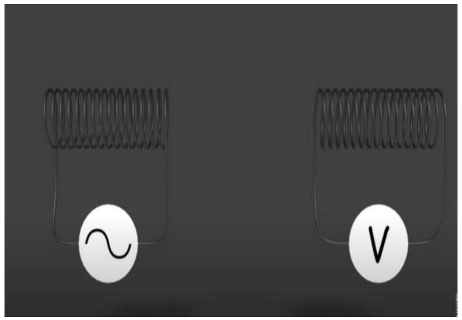
Fig.1: Motor Stator and Rotor

- A **rotor** is a rotating part of the AC motor
- The **stator** is the fixed or stationary part of the motor

Faraday's law of electromagnetic induction

- Faraday's law states that a current will be induced in a conductor which is exposed to a changing magnetic field





Faraday's law of electromagnetic induction

- The flux from the stator cuts the short-circuited coil in the rotor
- As the rotor coils are short-circuited, according to Faraday's law of electromagnetic induction, the current will start flowing through the coil of the rotor
- When the current through the rotor coils flows, another flux gets generated in the rotor.
- Now there are two fluxes, one is stator flux, and another is rotor flux.
- The rotor flux will be lagging in respect of the stator flux. Because of that, the rotor will feel a torque which will make the rotor to rotate

STEPPER MOTOR

- A stepper motor is a special electrical machine which rotates in discrete angular steps in response to a programmed sequence of input electrical pulses.

Working Principle

- A magnetic interaction takes place between the rotor and the stator, which make rotor move.

Construction

- The stator has windings
- The rotor is of salient structure without any windings

Types of Stepper Motor

1. **Variable Reluctance SM**

Reluctance:the resistance to magnetic flux ,offered by a magnetic circuit

2. **Permanent Magnet SM**
3. **Hybrid SM**

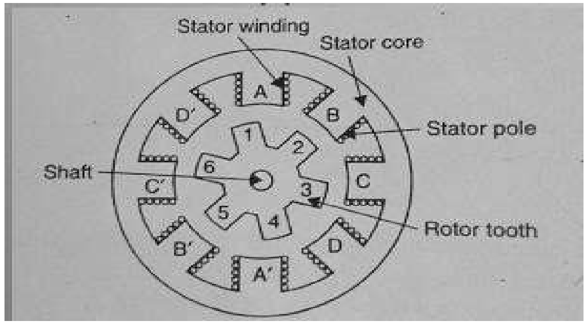
Application

Application of stepper motor in diverse areas ranging from a small wrist watch to artificial satellites.

- Power range 1W to 2.5KW
- Torque range 1µN to 40 Nm

Variable reluctance motor

- Variable reluctance stepper motor works on the principle that a magnetic material placed in magnetic field experience a force to align minimum reluctance path



Rotor teeth can be assume any position until the stator winding energised.For a four phase ,eight pole single stack VR steeper motor operation truth table given below and the angle rotate by rotor is given by

Φ=360/MxNr degree

Where

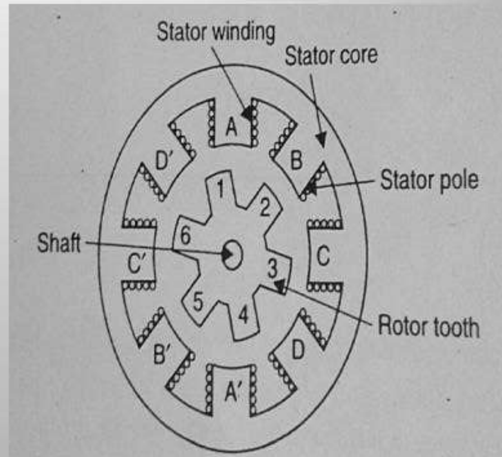
M = the number of stator phase

N= the number of rotor phase

In the present case M=4,Nr=6

Φ=360/4x6 degree

Φ=15 degree



1.1 Four-phase, eight-pole single-stack VR stepper m

Switching sequence

Phase	S-1	S-2	S-3	S-4	Angle (Deg)
A	1	0	0	0	0
B	0	1	0	0	15
C	0	0	1	0	30
D	0	0	0	1	45
A	1	0	0	0	60

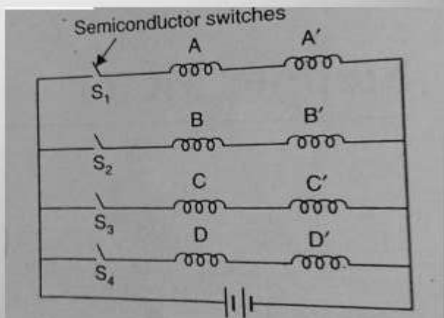


Fig. 1.2 Switching circuit

Rotor position for phase excitation

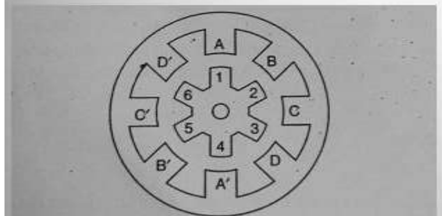


Fig. 1.3 Rotor position when phase A is excited

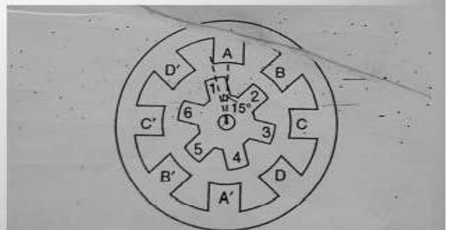


Fig. 1.4 Rotor position when phase B is energised

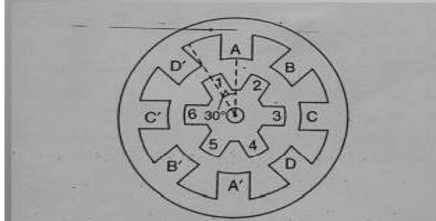


Fig. 1.5 Position of rotor after switching phase C

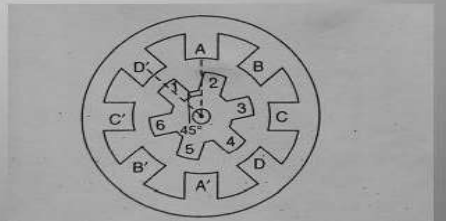
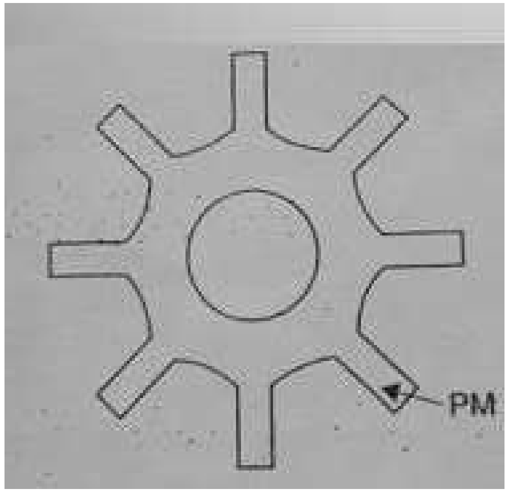


Fig. 1.6 Rotor position after switching phase D

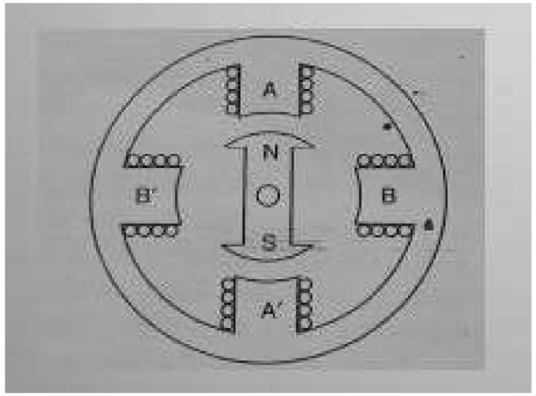
Permanent Magnet Stepper motor

- Permanent magnet (PM) stepper motor is another version of stepper motor
- Its construction is similar to that of a VR stepper motor.
- Stator consist of a salient poles wound with concentric coils.
- The rotor carries no winding but has permanent magnets.



- Due to the difficulty in manufacturing small PMs, the number of poles in the rotor is limited and the step size is relatively large in the range 300 to 900

Working..................



- To study the principle of operation of PM stepper motor, a two phase motor is considered.
- It has four stator poles and two rotor poles.
- The stator has winding on its poles.

•When a phase is energized, it sets up a magnetic flux and rotor will position to lock its N pole and S pole to stator S pole and N pole respectively.

Hybrid stepper motor

- Its operation based on the combined principle of both PM and VR stepper motor.

•HSM is the best choice for the application where small step angles and high starting torque are essential.

Working......

Consider a four pole, two phase HSM with 15 rotor teeth on each rotor section,as shown in figure.

Hybrid stepper motor

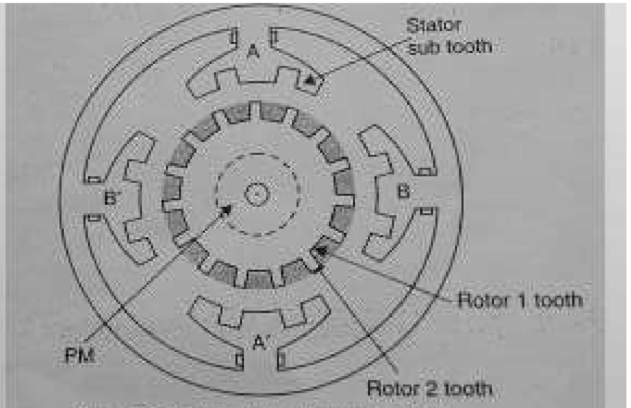


Fig. 1.23 Two-phase, four-pole HSM

- •Coils wound on poles A and A’ are connected in series to form phase A same as for phase B.
- •The step angle is 360/(2x2x15)=60
- •The tooth pitch is 360/15=240

References......

- https://www.linearmotiontips.com/how-does-the-number-of-stator-phases-affect-stepper-motor-performance/

MRT 204
SENSORS AND ACTUATORS

Magnetic sensors

Linear and Latching Solenoid Actuators

Magnetic sensors

- The magnetic sensors that are most commonly used in mechatronics systems today are

1) VR magnetic sensors
2) solid-state sensors
   - Hall-effect
   - magnetoresistive (MR) sensors

- Over the last 10 years, the number of sensors installed in the average automobile has risen from several up to the current 20

Application of magnetic sensors in a car

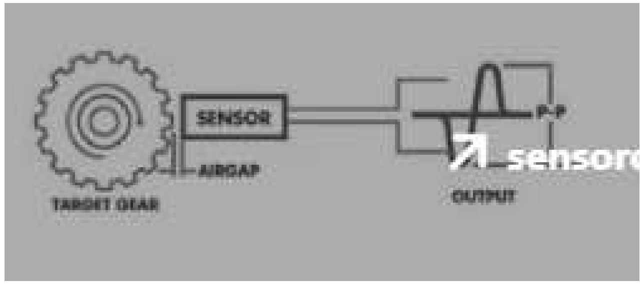
- ignition timing
- power sensing
- valve position
- current sensing
- linear or rotary motion detection
- speed sensing
- length measurement
- flow sensing
- revolutions per minute (rpm) sensing
- security systems, and more

VR magnetic sensors

- A **variable reluctance sensor** (commonly called a **VR sensor**) is a sensor that measures changes in magnetic reluctance.
- When combined with basic electronic circuitry, the sensor detects the change in presence or proximity of ferrous objects.
- Completely self-powered, VR magnetic sensors are simple, robust devices that do not require an external voltage source for operation
- They feature noncontact, error-free conversion of actuator speed to output frequency, as well as simple installation, with no moving parts.

Types of VR Magnetic Sensor
1) Analog VR sensors
2) Digital VR Sensor

- The drawback of VR sensors is that they generate a signal proportional to the magnetic field's rate of change.
- Therefore, the signal strength decreases with decreasing speed and, below a certain flux change rate
- A signal level is a function of the air gap between the sensor and a toothed exciter wheel.



- magnetic pickups
- speed sensors
- motion sensors
- pulse generators

Solid-state sensors

- Neither the **Hall-effect** nor the **magnetoresistive (MR)** sensors can generate a signal voltage on their own and must have an external power source. Therefore, they are called **active sensors**
- Solid-state sensors produce either a **digital** or an **analog** output.
- **Digital solid state sensor are sub divided into:**
  - bipolar
  - Unipolar
  - omnipolar.
- Bipolar sensors require a positive magnetic field strength (south pole) to operate and a negative one (north pole) to release.

- Omnipolar sensors operate with either north or south poles.
- Unipolar sensors require a single magnetic pole (south pole) to operate; the sensor is released when the pole is removed.
- Analog sensors operate in proximity of either magnetic pole
- Hall-effect circuitry measures speed accurately to true zero, direction of rotation or travel, and true angular position of gear.

The drawback

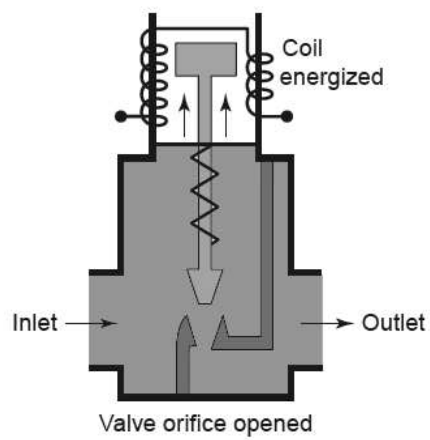
- Hall-effect devices generate a very small raw signal because of low field sensitivities
- performance is strongly temperature dependent.

Magnetoresistance

- Magnetoresistance is a material property which reflects its change of resistance when exposed to a magnetic field.
- These sensors measure the angle direction of a field from the magnet.
- They provide an absolute reading from the moment they are turned on; they do not need to be zeroed to an external reference.

Linear and Latching Solenoid Actuators

- A solenoid consists of a coil with magnetic wire wound on a bobbin with a moving armature and a return spring encapsulated within the housing.



- Depending on an armature’s shape, solenoids can be categorized as
  - plunger
  - disk
  - ball
  - conical types
- When electricity is applied to the coil, the resulting magnetic field attracts the armature and pulls it into the solenoid body against an armature stop, contracting a return spring
- When electricity is removed, the solenoid plunger is allowed to return to its original position due to a return spring or gravity

Solenoids are typically classified

- alternating current (AC)
- direct current (DC)

❑Another classification

❑linear

❑Rotary

Based on position

- On –off
- variable positioning

- The electromotive force (EMF) is supplied by the current applied to the coil and is limited by the heat dissipation capacity of the coil.
- The duty cycle, or the percentage of time that the solenoid is powered, is therefore a crucial factor in solenoid selection

Solenoid actuators

- Solenoid actuators transform electrical energy into mechanical energy. Depending on function, there are three types of solenoid actuators

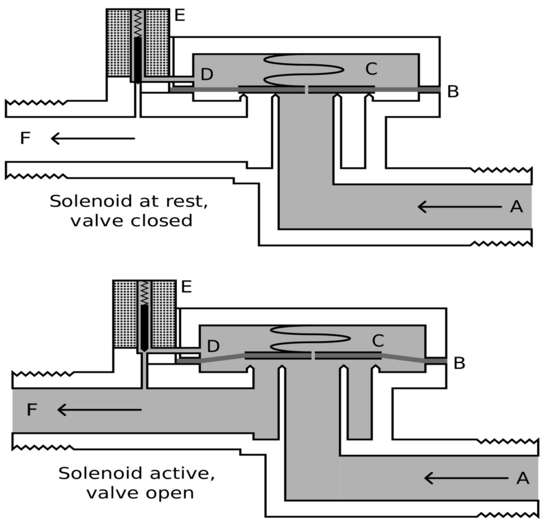
1) rotary solenoid with shaft rotary motion

. A rotary solenoid is an electromechanical device that converts linear motion to rotary motion

2) linear solenoid with linear motion

- Single-acting linear solenoids
- Two-directional linear solenoids
- Bistable solenoids

3) holding solenoid with holding force



- Single-acting linear solenoids — solenoid force developed in one direction, return action is effected mechanically, e.g., with a coil
- Two-directional linear solenoids — motion is effected by specifically energizing the respective coil
- Bistable solenoids — switching is effected with a current impulse of varying polarity, the end positions are maintained without current

linear solenoids are used to operate pistons and valves for accurate control of fluid pressure or flow in applications such as transmissions and fuel injection.

- **proportional solenoid**

A **proportional solenoid** is a linear actuator with a fixed range of travel where the value of the input signal corresponds to the solenoid travel distance. The proportional solenoids can control position in a precise manner.

Latching solenoid

- A solenoid can also be made in a magnetic latching style
- a magnet is used inside the solenoid body.
- When the coil is energized and the armature is pulled into the solenoid body, the magnet holds the armature in position even after the power is removed.
- A reverse voltage is then applied to release the armature from the solenoid body to allow it to return to the starting position

MRT 281:INTRODUCTION TO SENSORS AND ACTUATORS

Special Magnetic Devices

Rotary and Linear Actuators

Magnetic Materials and Technology

Special Magnetic Devices

- Devices with unique medical applications such as an electronically controlled heart valve or a ventricle assist artificial heart pump were selected for this review
- Challenges faced while designing:
  - energy supply
  - heat dissipation
- long-lasting energy supply helps reduce the number of surgeries between implants
- proper heat transfer helps tissues survive longer.

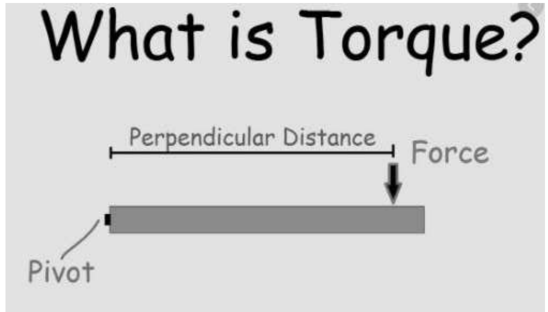
- Maintaining the temperature rise below 3–5°C above normal body temperature (36.6°C) is critical because such a relatively small temperature increase may permanently damage exposed tissue cells.
- Another challenge is selecting the device location and its size.
- Even though the heart valve final design met all the required temperature and blood pressure tests, its design has a number of deficiencies in comparison with a real human mitral valve:
- Excessive noise when in operation
- Blood cell damage, inducing blood clots
- The need to dissipate heat that may damage cells
- Large volume with its sewing ring and electromagnetic circuit
- Requires electrical energy to run
- Need for connections and leads
- Limited durability, up to 10 years

- Piezoelectric, Magnetostriction, rheological, and thermo-responsive materials have perhaps the highest potential for use in mechatronic systems.
- **Magnetostriction:** change their shape or dimensions during the process of magnetization
- **Rheology**: change the physical state
- Piezoelectric ceramic and polymer materials that instantly change the physical shape in response to an electrical field have potential use in actuators that control vibration in precision tools, and improve accuracy and speed of robotics, printers, and injectors.
- Devices with electro strictive and magneto strictive materials that change size in response to either electric or magnetic fields, or that can produce electrical voltage signals when stretched, can be utilized as valves and pumps or sensors.

- Electrorheological and magnetorheological fluids that change their states from liquid to almost solid in the presence of electrical or magnetic field
- applications in dampers for automotive suspension with great potential for medical, construction, and sport utility applications, among others.
- Thermo responsive materials, such as shape memory alloys that change shape in the presence of cold and heat, were found useful for automotive and aircraft parts such as couplers and thermostats.

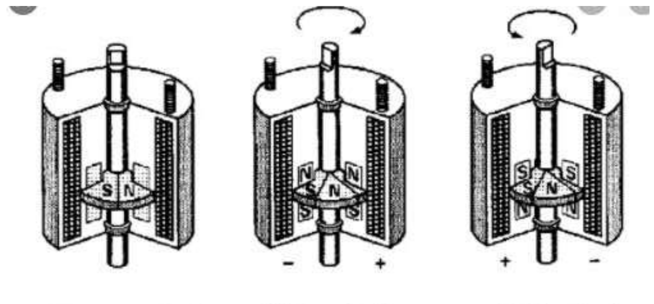
Rotary and Linear Actuators

- Rotary actuators, also called torque motors or torque actuators, are electromechanical devices that develop torque with limited-angular travel.
- **Torque** is the measure of the force that can cause an object to rotate about an axis.



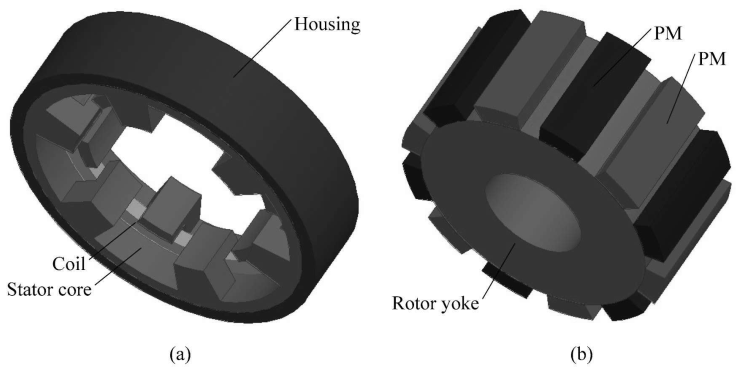
- Linear actuators are force motors that develop force with limited linear travel.
- Both linear and rotary actuators are aimed at developing high force density over the limited movement of the armature.
- For rotary actuators, a PM armature with multipole magnetization is sandwiched between two VR toothed stators for a high-density torque with a magnetic gearing effect

- 1.Disk rotary actuators with a multipole axially magnetized disk magnet sandwiched between two VR homopolar stators



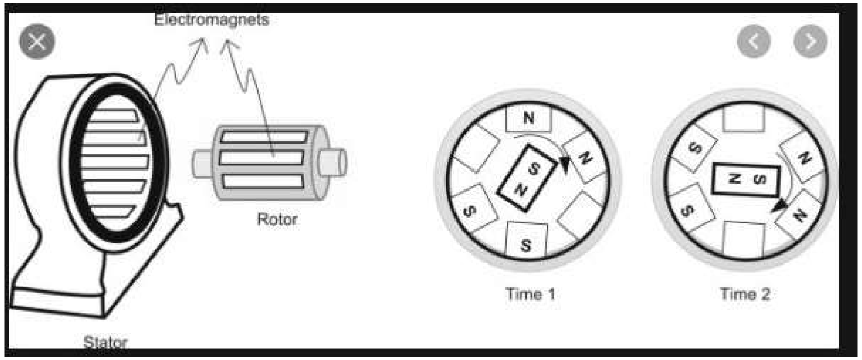
(a) De-energized (b) Energized (c) Energized

- Claw pole rotary actuators with a multipole ring magnet and a claw pole stator homopolar stator



(a) (b)

- 3. Cylindrical rotary actuators with a multipole radially oriented ring magnet with an inside and outside VR monopolar toothed structure



Magnetic Materials and Technology

- The interaction of matter with an external magnetic field divides magnetic materials into three categories: diamagnets, paramagnets, and ferromagnets
- diamagnets do not respond to the presence of the external magnetic field
- paramagnets are materials that weakly magnetize in the same verse as the magnetic field
- Ferromagnets are materials that weakly magnetize themselves in opposite verse to the magnetic field.

Coercivity: the resistance of a magnetic material to changes in magnetization, equivalent to the field intensity necessary to demagnetize the fully magnetized material.

- **ampere-turn** per meter (AT/m)

- Depending on coercivity, there are two types of magnetic materials
- 1. **Soft magnetic materials** — when coercivity is lower than 1000 At/m; they have the ability to amplify hundreds of thousands of times the external magnetic field.
- 2. **Hard magnetic materials or PMs** — when coercivity is higher than 1000 At/m; they have the ability to keep their magnetism permanently and to store in their volume hundreds of kilojoules per cubic meter of energy.

- Ferromagnets are substances that can be induced to become magnetized in a magnetic field.
- **Soft ferromagnetic** - materials become demagnetized spontaneously when removed from a magnetic field with a relatively small remanent magnetization.
- Hard ferromagnetic materials can retain their magnetism, making them useful in the production of PMs.

BASICS.... OF Magnetism

- A magnetized magnet contains a north and a south pole that develop a magnetic field.
- Similar magnetic poles repel and opposite magnetic poles attract. A magnetic field is a region in space where a magnetic force can be detected.
- The magnetic field is strongest at the poles of a magnet. Magnetic lines of force are a way of representing a magnetic field.
- By convention, magnetic lines of force point from north to south outside a magnet and from south to north inside a magnet. Magnetic lines of force form complete loops, which never cross.

MRT
204:SENSORS AND ACTUATORS

Soft Magnetic Materials

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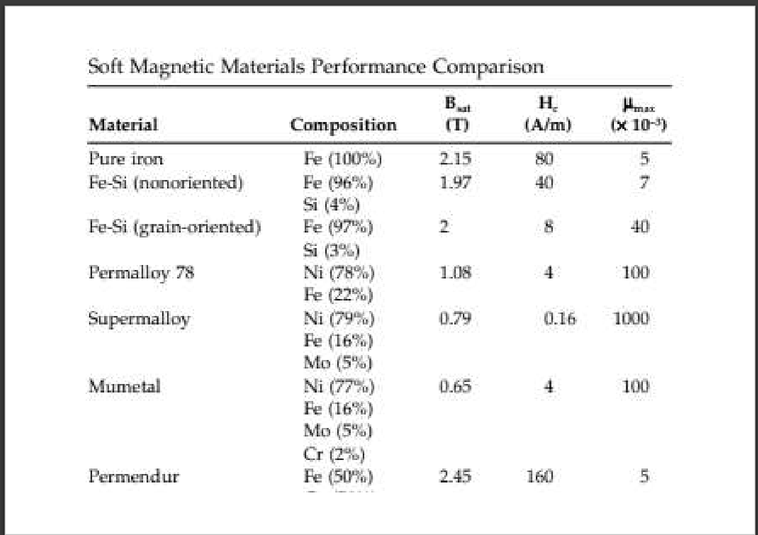
Soft magnetic materials

- Soft magnetic materials are mainly utilized in applications in which magnetic materials are needed to amplify the flux generated by an electrical current or by a PM.
- The principal characteristics of soft magnetic materials are remanence, coercivity, maximum and initial values of permeability, saturation value of flux density B, and coercive force H
- **Remanent=remaining after the magnetizing field has been removed.**
- **In electromagnetism, permeability is the measure of the resistance of a material against the formation of a magnetic field**



Soft Magnetic Materials Performance Comparison

Material	Composition	B_{sat} (T)	H_c (A/m)	μ_{max} ($\times 10^{-3}$)
Pure iron	Fe (100%)	2.15	80	5
Fe-Si (nonoriented)	Fe (96%) Si (4%)	1.97	40	7
Fe-Si (grain-oriented)	Fe (97%) Si (3%)	2	8	40
Permalloy 78	Ni (78%) Fe (22%)	1.08	4	100
Supermalloy	Ni (79%) Fe (16%) Mo (5%)	0.79	0.16	1000
Mumetal	Ni (77%) Fe (16%) Mo (5%) Cr (2%)	0.65	4	100
Permendur	Fe (50%)	2.45	160	5

- Soft iron is utilized in the form of solid bars, sheets, and, most recently, as a powder.
- Powder-metal soft magnetic materials also can be used in their sintered form.
- The development of these materials in the last decade has been spectacular due to advances in powder-metal technology.
- They are applied in such devices as peripheral computer devices, printer actuators, brake assembly in disk drives, voice coil actuators, or VR sensors in the automotive industry
- There are a number of technical and economic advantages for using sintered powder soft magnetic material:

- Wide range of materials available to designer
- Possibility of obtaining complex and varied shapes
- Process repeatability easily controlled by statistical methods
- Tolerance reliability
- Present magnetic characteristics close to fully dense materials
- Possibility of material composition unattainable by other technologies
- Near integral use of material with little or no machining
- Clean, safe, nonpolluting economic production process
- Flexible production process allowing for good applications of the just-in-time lean manufacturing methods

- For the applications requiring maximum induction, cobalt-iron, phosphorus-iron, and pure iron powder metal are recommended.
- For dynamic applications demanding rapid magnetic flux change, such as relays or injectors, the phosphorus-iron and silicon-iron materials are recommended because of their high-electrical resistivity, which suppresses the eddy currents.
- For the applications where high magnetic induction must be achieved in a short period of time with a low excitation current, the nickel iron with maximum permeability is recommended

- Two categories of soft magnetic materials can be recognized based on the DC and AC applications.
- DC applications of soft magnetic materials require a low coercivity Hc and a high permeability
- A low coercivity value is necessary to avoid remanence after the magnetic field is applied, when the power switches are off and a high value of permeability is needed to enhance the excitation field H.
- The most common DC applications are for electromagnets and yokes, relays, magnetic shields, electrical measuring devices, and magnetic amplifiers.

DC applications

- Iron and low-carbon steels
- Iron-nickel alloys
- Iron-cobalt alloys

AC applications

- AC applications of soft magnetic materials require a low coercivity H_c and a low power loss, a high permeability μ_{max}, and a high saturation magnetization
- AC applications include transformers, motors, and generators, as well as signal transmitters and receivers.
- Iron-silicon alloys
- Iron-nickel alloys
- Soft ferrites

Assignment

- Hard Magnetic Materials

MRT 204: SENSORSAND ACTUATORS

Coating Technologies

Magnetic Materials Market and Applications

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Coating Technologies

- Corrosion continues to represent a challenging issue for magnet manufacturers because of the wide range of applications in severe environments .
- Coatings for sintered and bonded magnets include:
  - nickel plating
  - organic electrocoating
  - spray coatings
  - multiple layers of combination coatings for tough performance requirements.

- Some companies developed an improved coating process where magnetic particles are encapsulated with organic coatings.
- Some companies developed an even more advanced coating process with precise functional characteristics by applying thin multiple coatings over individual powder particles
  - Corrosion protection before, during, and after magnet manufacturing
  - Extremely uniform metal distribution with reduced geometric or dimensional scattering
  - Higher magnetic properties of the manufactured magnet
  - Minimized magnetic temperature degradation

Advantages of Coating

- This coating process, therefore, allows for reducing magnet manufacturing costs by eliminating expensive compounding and blending costs
- increasing production throughput
- reducing rejects
- and eliminating the need for secondary coatings in some applications.

Magnetic Materials Market and Applications

- Magnets serve as essential components in almost all domestic and industrial applications in the automotive, instrumentation, production machinery, aviation, marine, and space markets.
- Magnets are used in computers, electric motors, loudspeakers, smartcards, cell phones, tape recorders, cameras, camcorders, compact disk players, microwave ovens, kitchen robots, refrigerators, and washers and dryers, to name a few consumer products.
- Their contribution is often ignored because they are built into devices and are usually out of sight

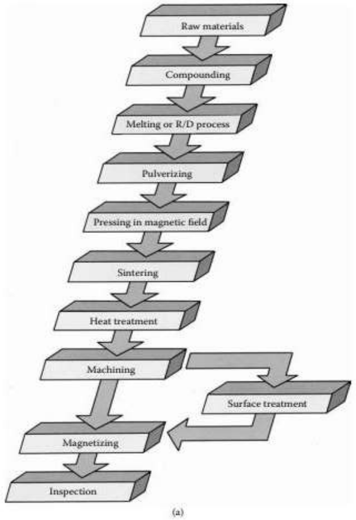


FIGURE 1.3
Rare-earth magnet manufacturing process: (a) sintered-based. (From Hitachi Metals Ltd., Hitachi Rare-Earth Magnets, 1999. With permission.)

- Magnets function as transducers and energy conversion devices, transforming energy from one form to another without any permanent loss of their energy.
- Energy conversion devices utilize PMs to convert mechanical-to-mechanical energy as attraction and repulsion motion
  - mechanical-to-electrical energy as generators and microphones
  - electrical-to mechanical energy as motors
  - Loudspeakers
  - mechanical energy to heat as eddy current

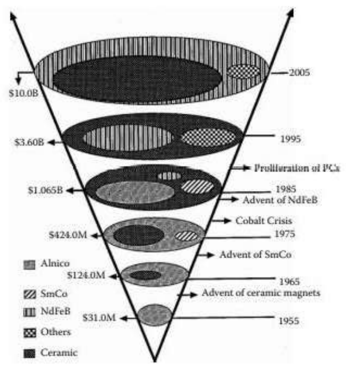


FIGURE 1.4
Growth of the PM market. (From Rashidi, S., NdFeB Opening Remarks, NdFeB '99 Conference, San Francisc April 12–14, 1999, p. 3. With permission.)

1)ferrite ceramic magnets
2)alnico alloys
3)rare-earth samarium-cobalt
4)neodymium magnets
5)others

- **Magnet manufacturers maintain that the following current trends in automotive system design should affect rare-earth magnet growth opportunities by increasing the penetration of electric motors in automobiles:**
- Electronic control of motors
- Power-generation technologies
- Motor technologies
- Minimizing parasitic engine losses
- Worldwide supply considerations

- **Cost, temperature, and manufacturing are the major barriers to the expanded use of neodymium magnets in automobiles**
- Cost barriers — neodymium not yet considered a ceramic replacement because of cost, system integration has potential in savings to offset system cost
- Thermal barriers — under-hood temperatures affected by engine compartment complexity, effect of operation and location of other heat-generating subsystems, component self-heating, and difficulties with predicting operating temperatures accurately
- Manufacturing barriers — feasibility of high volume production, fragile aspect of neodymium material, magnetizing and calibrating assembly, and difficulty of repair or rework

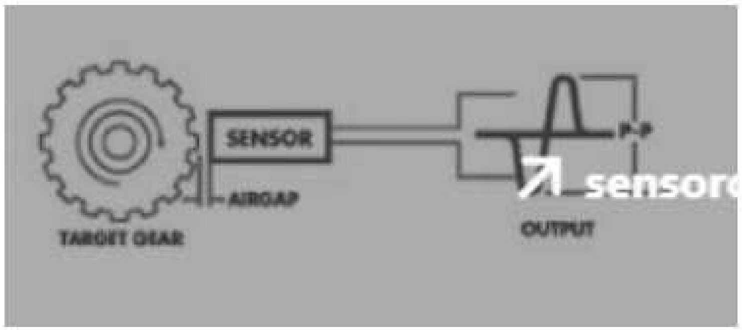
MODULE 2

MRT 281 INTRODUCTION TO SENSORS AND ACTUATORS

MAGNETIC SENSOR APPLICATION-
MAGNETIC SPEED SENSOR REQUIREMENT-
MAGNETIC SPEED SENSOR APPLICTION-
MAGNETIC POSITION SENSOR APPLICATION-
VR SENSOR NOISE

MAGNETIC SPEED SENSOR REQUIREMENT

- Typical VR sensor requirements for automotive applications pertain to the sensor signal, usually defined as the peak-to-peak value, its geometry, speed range, temperature range, and the acceptable noise level.



MAGNETIC SENSOR APPLICATION

- The applications of magnetic velocity sensors are increasing rapidly, particularly in the automotive industry.
- where they are used for:
  - ABS
  - TC
  - four-wheel drive
  - steering wheel
- VR speed and position sensors are widely used in industry and, in particular, the automotive industry because of their low cost and high reliability.

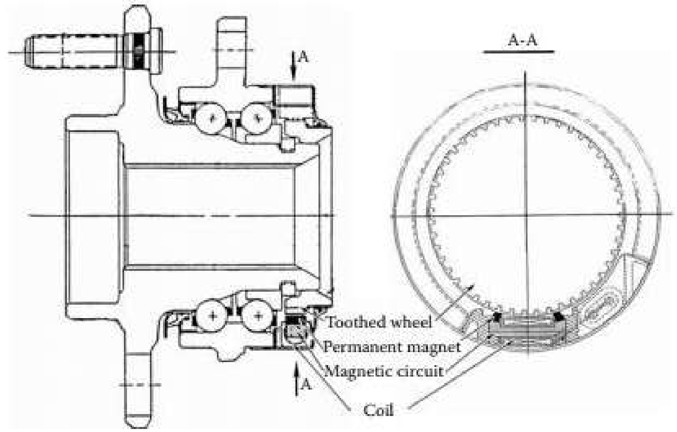


FIGURE 2.73
Two-magnet sensor integrated with the wheel bearing for ABS.

MAGNETIC SPEED SENSOR APPLICTION

- Figure 2.73 shows a two-magnet sensor applied to the wheel speed sensing application for the ABS system.
- The sensor fits under the grease cover that is a part of the wheel bearing and provides a signal to the ABS system.
- The particularly difficult sensor environment with high ambient temperature around the brakes led also to the selection of a magnet material that is stable at elevated temperatures.
- **CONSTRUCTION:**
- magnetically distributed ring-shape sensor with multi-pole magnet that fits best and could be integrated within the bearing grease cover, and its magnetic distribution nature would help compensate for the radial tolerances.

FIGURE 2.74
Magnetically distributed sensor integrated with wheel bearing.

- This enables this sensor to provide signals for both the ABS and TC system with a much more difficult requirement to meet.
- The magnetically distributed sensor, shown in Figure 2.74, can provide a full signal of 1.0 V at the wheel speed of 0.25 mph.
- however, the two-magnet sensor capability at full signal is limited to 0.9 mph vehicle speed, which is sufficient for ABS but not satisfactory for the TC.
- During the development of the two-magnet sensor integrated with the wheel bearing for the ABS, meeting all requirements was quite a challenge. For this modern sensor structure, shown in Figure 2.73, additional improvement was introduced by heat treatment of the magnetic parts.

MAGNETIC POSITION SENSOR APPLICATION

- The front-mounted-magnet sensor in Figure 2.76 is presented with an exciter wheel that has a particular tooth and slot pattern that would provide accurate crankshaft position.
- There are two such sensors adopted for this application to provide additional information on the direction of rotation.
- The rotation of the wheel creates a change in magnetic flux linkage in the sensor, which generates a voltage signal based upon the flux rate change.

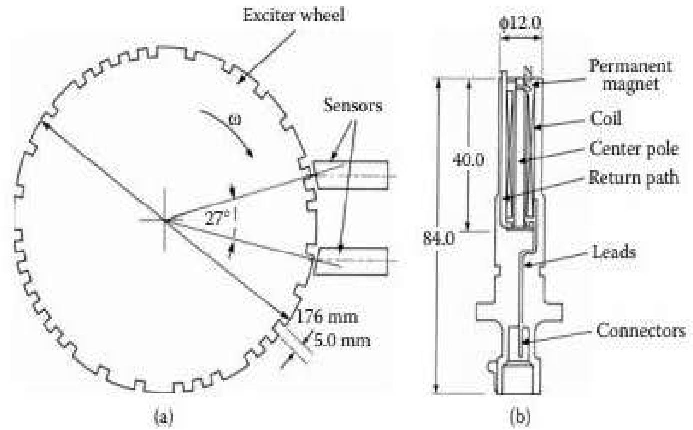


FIGURE 2.76
Front-mounted position sensor: (a) sensor-wheel arrangement, (b) front-mounted sensor.

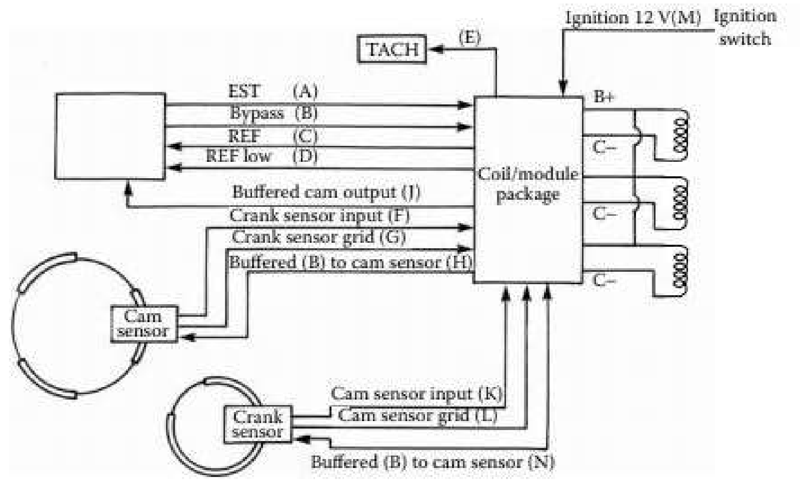


FIGURE 2.77
Crankshaft position sensor. (From Pawlak, A.M., *Proceedings of the NdFeB '99 Conference*, San Francisco, April 12–14, 1999. With permission.)

- The electronic module, shown in Figure 2.77, processes the signal from the sensor to determine a crankshaft position and engine speed.
- It responds to voltage transmissions generated in the sensor by the slotted wheel passing by.
- This voltage must rise above a certain positive threshold and then move through zero volts on negative transition.
- The positive threshold varies from 250 mV at minimum cranking speed of 40% of the previous positive peak.

- The module counts the time between zero-crossing events of the sensor to determine the engine speed and the crankshaft position.
- The special slot distribution of the wheel allows recognition of the crankshaft position at its half revolution.

VR SENSOR NOISE

- In automotive applications, a VR sinusoidal sensor signal, as presented in Figure 2.78, is filtered and squared by a remote buffer circuit, whose output can be used by the speedometer, cruise control, TC, and other systems.
- Because it is not possible to determine the level of noise signal before the sensor is built and applied, usually it is a matter of sensor modifications after the sensor is designed and tested.
- Sometimes the same sensor applied to one environment's noise level is acceptable, yet in a new arrangement may not be acceptable.

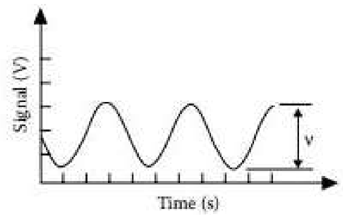


FIGURE 2.78
Sensor signal vs. time.

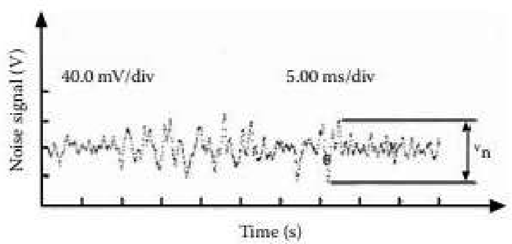


FIGURE 2.79
Noise signal vs. time.

- Noise should be measured at the worst conditions: highest temperature, highest engine rotation, and for sensor position when the flux linkages are at their maximum values (wheel tooth vs. pole tip).
- Under extreme conditions, the noise signal vs. time characteristic should be determined for the original sensor.
- A typical example of the noise vs. time characteristic is presented in Figure 2.79. In this example, the transmission speed sensor noise signal was recorded at 5000 rpm of engine speed at transmission gear in neutral or park position.
- Because the vehicle is not moving, the sensor signal should be zero as well as the speedometer reading.

- **Noise Problem Solutions:**
- The investigated sensor was applied to two different automotive power train transmissions, as presented in Figure 2.80. Because the axial length of the exciter wheel is different.

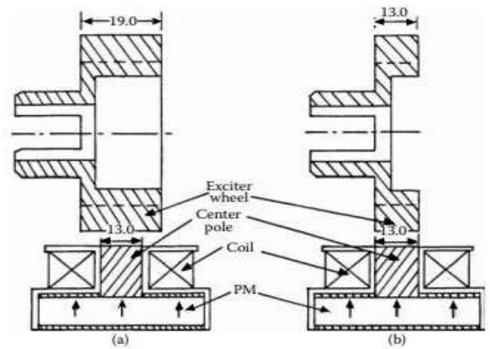


FIGURE 2.80
Sensor-wheel arrangements for two different power train transmissions: (a) wide exciter wheel, (b) narrow exciter wheel.

- **the transmission with the shorter exciter wheel is more sensitive to axial vibrations.**
- Therefore, a vehicle equipped with this exciter wheel was found to have the most severe noise signal problem and was selected for experimental noise evaluation of sensor prototypes.
- The voltage signal can only be generated in the coil as a result of a change in the flux linked with the coil.
- **If the analyzed sensor is installed on a vehicle and the vehicle is stationary, this change in flux linkages can result from engine vibration**, causing a relative motion between the sensor coil and the transmission speed sensor components of the sensor assembly:

SOLUTIONS IMPLEMENTED

- The first step is to mechanically couple, by cementing all internal sensor components, and measure noise signal on a relatively large number of sensors (50).
- A large number of speed sensors should be tested because of unrepeatable test conditions. In the examined case, cementing internal parts resulted in 30% of noise reduction.
- It was assumed that the remaining 70% of their noise is due to vibration of the exciter wheel with respect to the speed sensor assembly, which can be reduced by using tighter exciter wheel tolerances.

- However, cementing components and tightening the tolerances are both costly alternatives, so we started looking for other solutions.
- **Three areas of the sensor geometry were considered — geometry of the center pole, coil design, and air gap length.**
- Unfortunately, any changes in the **pole design** that were considered show no measurable improvements in the signal to noise ratio.
- The **coil design** study was conducted for full available coil space (window) utilization with different coil wire sizes.

- The results of these considerations :
  - **The noise-to-signal ratio is reduced for thicker wire.**

  The influence of the length of the air gap between the sensor and the sensor assembly was investigated:

  It was found that the noise decreases three times faster than the signal as the air gap increases. Therefore, this can be considered a very effective way to reduce noise.

Observation:

- Even though the sensor signal level is determined by the geometry of the wheel, its angular speed, and the length of the gap
- **the noise is generated due to vibrations that cause variations of magnetic permeance that are independent of the wheel geometry and depend mainly on the air gap length and its variation with respect to the time. Therefore, the noise is more sensitive to air gap variation than the sensor signal.**
- **Note:** In a magnetic circuit, permeance is a measure of the quantity of magnetic flux for a number of current-turns.

MODULE 3

MRT 281
Introduction to Sensors and Actuators

Fast-Acting-Actuators-Disk Solenoids-Plunger Solenoids-Ball Solenoids-Conical Solenoids-Application Of Solenoid Actuators

Presented By
Arun Jose
Assistant Professor
Mechatronics

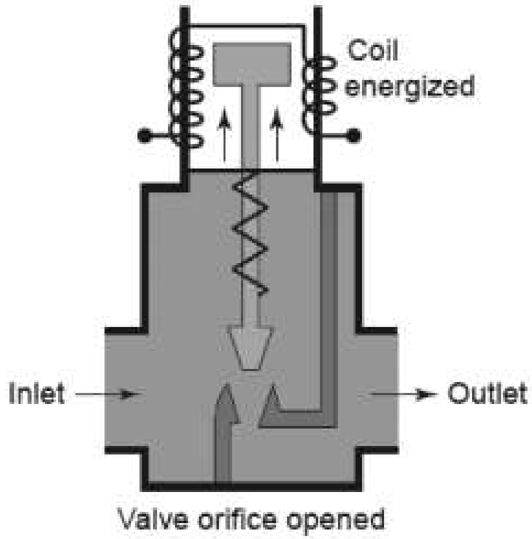
Solenoid actuators

- Solenoid actuators transform electrical energy into mechanical energy. Depending on function, there are three types of solenoid actuators.
- A solenoid consists of a coil with magnetic wire wound on a bobbin with a moving armature and a return spring encapsulated within the housing.
- When electricity is applied to the coil, the resulting magnetic field attracts the armature and pulls it into the solenoid body against an armature stop, contracting a return spring

- When electricity is removed, the solenoid plunger is allowed to return to its original position due to a return spring or gravity.
- Depending on an armature's shape, solenoids can be categorized as.
- Plunger Solenoid
- disk Solenoid
- ball Solenoid
- Conical Solenoid

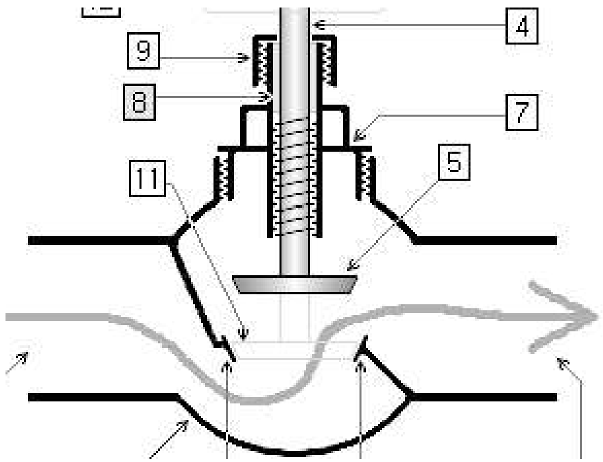
Characters considered

- the stationary magnetic circuit
- the coil with the current source
- magnetic armature
- Additionally, the main air gap region can be specified separately to maintain a linear displacement of the armature



- the disk solenoid configuration has double the main air gap for flux to cross.
- At the same time, it has two relatively large surfaces of inner pole and outer magnetic circuit around a coil where flux is perpendicular to its surface.
- This promotes applications with small travel and fast action.
- A small travel would secure high solenoid electromagnetic efficiency, where large forces would help complete the travel distance in a relatively short period of time.
- Therefore, disk solenoids may find applications as injectors where all these attributes can be utilized.

Disk Solenoid

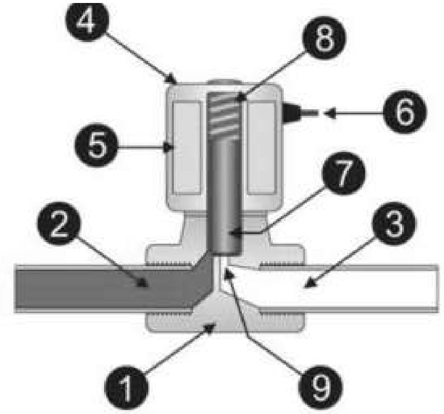


Plunger Solenoid

- Plunger solenoid types are the most popular solenoid configuration with a variety of applications.
- This is because the plunger solenoid configuration has a single main air gap for flux to cross and one **parasitic air gap** that is usually perpendicular to the main one.
- This promotes applications with small travel and fast action such as injectors and other fast-acting solenoids.

Ball-type solenoid

- Ball-type solenoid actuators can be applied in fluid control applications, such as automatic transmissions, due to their good sealing capabilities and response time.
- They are also used in applications where the ball armature, due to its inertia in a car crash, is separated from a PM ball stop and may be, therefore, used as an air bag deployment mechanism
- The ball solenoid configuration has limited applications that are also more difficult to analyze because of the shape of the armature

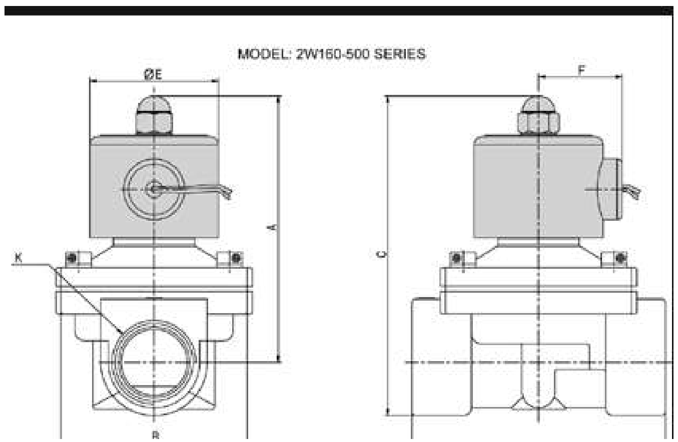


Parts of Solenoid Valve

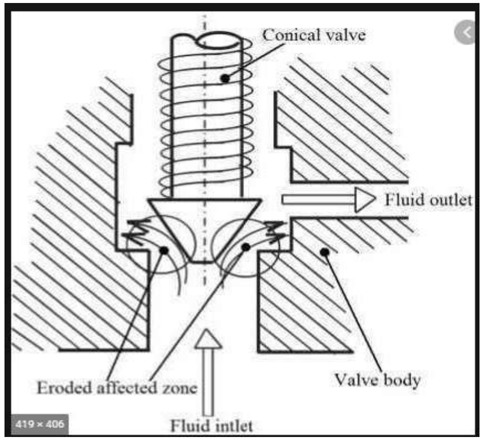
1) Valve body
2) Inlet port
3) Outlet port
4) Coil / Solenoid
5) Coil winding
6) Lead wires
7) Plunger or piston
8) Spring
9) Orifice

Conical Solenoids

- Conical solenoid actuators can be used in long stroke applications, such as in automotive door locks, due to their high force over long stroke capabilities.
- They can also be applied in situations where the armature can develop a relatively large force due to a smaller magnetic air gap than axial stroke.
- The conical solenoid configuration has limited applications in long stroke travel without fast response time.



- This is because the conical solenoid configuration has a single main air gap for flux to cross that is always smaller than mechanical travel distance and one parasitic air gap that is usually perpendicular to the direction of motion.



MRT 281
Introduction to Sensors and Actuators

Application of Solenoid Actuators-Long Stock Solenoid Fuel Pump-Gasoline injectors-Natural Gas Injectors

Submitted By
Arun Jose
Assistant Professor
Mechatronics

Applications ….

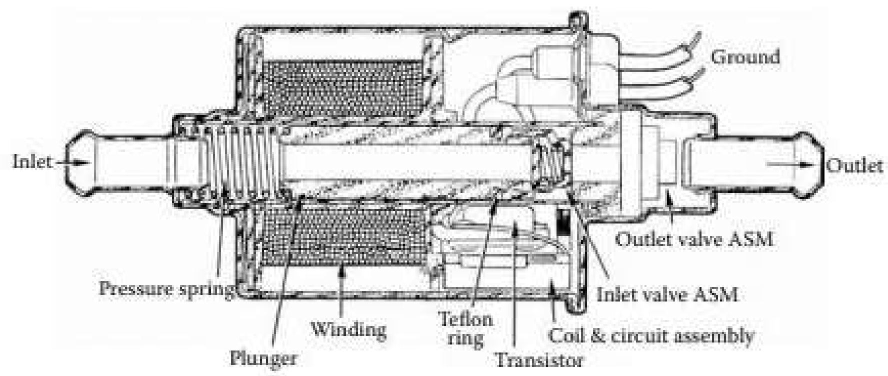
- Solenoid actuators are the most commonly applied electromagnetic devices in the automotive industry.
- They are used for **fast-acting operations** with a short stroke, such as gasoline, natural gas, and diesel fuel injectors or compressors, fuel pumps, and transmission solenoid valves.
- **For long stroke operations**, solenoid actuators are used in solenoid fuel pumps or door locks.

Long Stroke Solenoid Fuel Pump

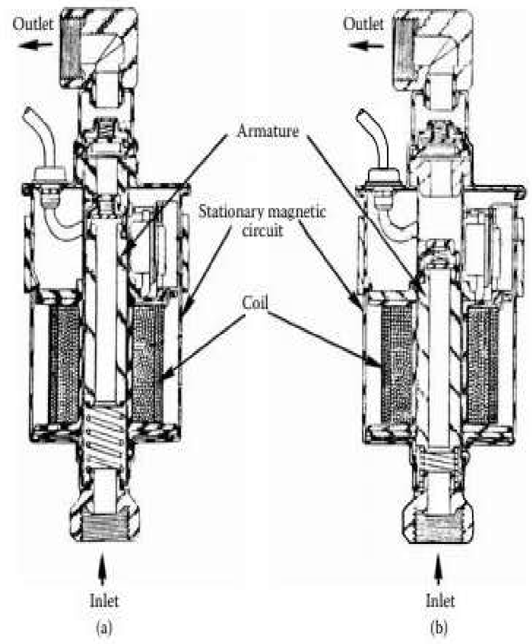
- Solenoid strokes with total travel of more than several millimeters fall into the long stroke solenoid category
- Most of them are conical where the total travel distance is larger than the magnetic air gap for the magnetic flux crossing. An example of this is a door lock solenoid.
- All other long stroke solenoids are plunger types with coil–plunger asymmetry and spring offset. A good example of this configuration is a solenoid fuel pump.

- A common application of electronic fuel pumps is an automotive diesel engine.
- The pump has very good priming capabilities and its proximity to the engine does not obstruct the pump from drawing fuel from the tank at the rear of the vehicle and delivering it to the engine.
- it has few moving parts and no points exposed to wear. It provides a quiet operation with proven durability
- The pump action of the fuel pump is created by the movement of the plunger inside the cylinder, which is completely sealed against the leakage.

- When electrical power is applied, the resulting magnetic force pulls the plunger piston down against the pressure spring

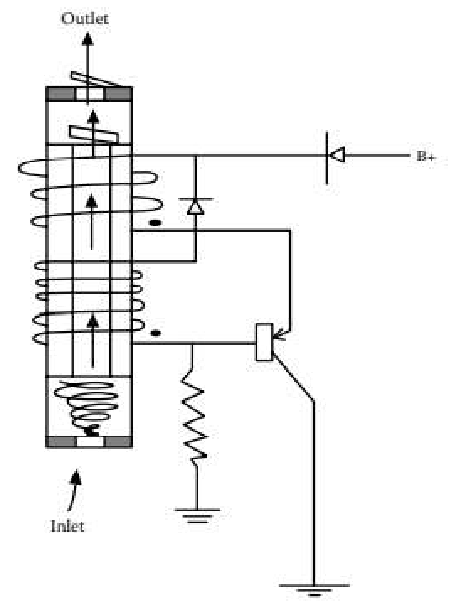


- The reason for this is the initial movable plunger location vs. the stationary coil that is not symmetrical to the coil and magnetic circuit.
- When the magnetic field is applied, it pulls the movable magnetic plunger to its center, trying to achieve the maximum magnetic permeance (and minimum magnetic reluctance) for the magnetic flux.
- As the plunger piston moves toward the spring, the outlet valve closes and the inlet valve opens.



- Fuel then enters the pumping chamber through the center of the piston. As the downward motion is completed, the magnetic field is turned off and the pressure spring forces the piston in the reverse position, as presented in Figure (b).
- At this time, the inlet valve closes, the outlet valve opens, and the fuel is released.
- This sequence occurs many times per second. As the pumping action continues, pressure on the outlet increases.

- As this pressure increases, the piston stroke decreases, and only the required amount of fuel is pumped to the engine.
- Fuel is confined to the pump cylinder and does not enter sections of the pump that contain the coil assembly and electronics.
- The electronic circuit shown in Figure indicates that the solenoid coil consists of two coils: the upper primary coil with 325 turns and wire size 12 AWG having 1.2 Ω, and the lower secondary coil with 164 turns and wire size 37 AWG having 300 Ω.

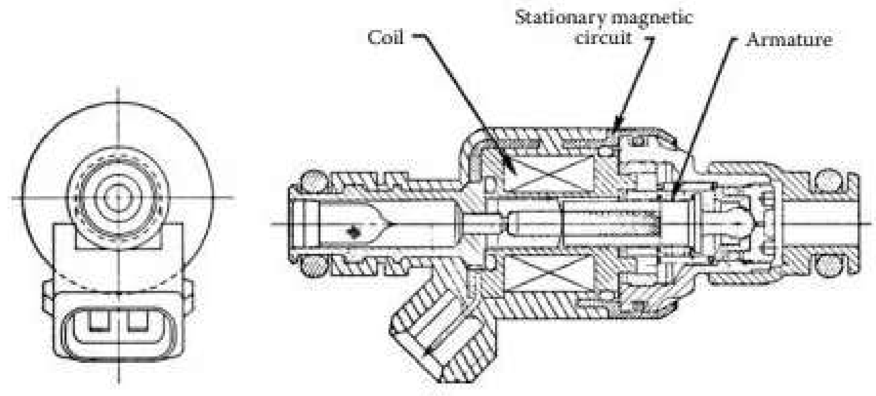


Gasoline Injectors

- Fuel injection performs better, provides crisper throttle response, improves fuel economy, allows much easier starts especially during cold weather, and produces much lower emissions than carburetors.
- These advantages led to the introduction of computer-controlled engine management systems with electronic fuel injection. Gasoline-powered engines with fuel injection do not use direct injection systems.
- but rather indirect systems that spray fuel into either the intake manifold or head ports.

- The injectors spray fuel into the intake manifold, where it mixes with air and is carried through the intake runners and ports to the engine’s cylinders.
- Nowadays, the multiport fuel injector or port fuel-injection systems are used, where a separate fuel injector is provided for each of the engine’s cylinders.

- The injectors spray fuel into the intake manifold, where it mixes with air and is carried through the intake runners and ports to the engine's cylinders.
- Nowadays, the multiport fuel injector or port fuel-injection systems are used, where a separate fuel injector is provided for each of the engine's cylinders.
- All advanced injection systems require better dynamic injector response—the opening and closing travel time.
- The world's first FE (finite element)dynamic optimization of the fast-acting solenoid with a moving part (plunger) was applied to the Multec injector, as illustrated in Figure.



(a)

- Pioneer dynamic optimization of the dynamic analysis of the Multec design was performed using FE techniques including eddy currents, nonlinear magnetic materials, and motion.
- Proposed magnetic modifications resulted in significant improvements in performance, making Multec an extremely competitive product that for more than two decades has been manufactured with a peak volume of 50 million units annually.
- This dynamic optimization technique has been successfully applied to many fast-acting, solenoid-based products to improve existing and help create new designs

Natural Gas Injectors

- The increasing cost of gasoline is driving interest in natural gas as a less expensive energy option for automotive use.
- As a result, natural gas injectors are finding more and more applications in the automotive industry.
- Figure shows a cross section of a typical natural gas injector that closely resembles a gasoline injector with its connector, coil, movable plunger, magnetic circuit, and return spring components.
- Natural gas injectors have to meet natural gas requirements for automotive applications ranging from small passenger car 1.6 l engines to large truck 6.0 l engines.

Source: Courtesy of Delphi Corp.

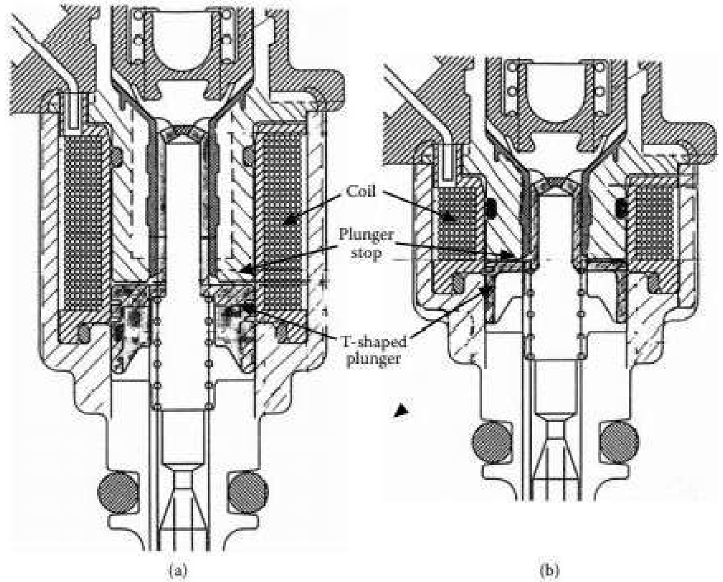


FIGURE 3.45
Natural gas injector with T-shaped plunger: (a) adopted T-shaped plunger, (b) optimized T-shaped plunger. (Courtesy of Delphi Corp.)

- The most difficult requirement is meeting the low voltage requirement of 6.0 V because an injector has to develop sufficient force to operate under the required pressure
- the conventional injector design did not meet this critical requirement and, in fact, stopped its operation at a voltage of 9.0 V.
- Because of this, a T-shaped plunger configuration was adopted, as shown in Figure 3.42(b) and Figure 3.45. For this design, almost the entire original structure of a typical injector was preserved, except in the area of the plunger stop and the T-shaped plunger, as presented in Figure 3.45(a)

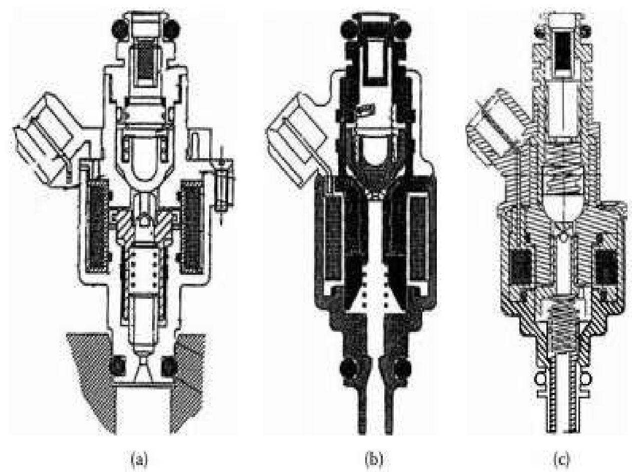


FIGURE 3.42
Natural gas injector designs: (a) conventional gas injector, (b) improved gas injector, (c) optimized gas injector (Courtesy of Delphi Corp.)

- The T-shaped plunger has a number of advantages over a hollow plunger armature, as presented in Figure 3.45(a).
- It has a relatively large active area in the vicinity of the main air gap that develops high magnetic forces and its thin walls allow for significant mass reduction and ease of manufacturing relative to the original plunger.
- At the typical automotive voltage of 13.5 V, the natural gas injector configuration with T-shaped armature has three times faster dynamic response time in comparison with the conventional hollow plunger injector design. This shows the dynamic potential of the T-shaped armatures.

MRT 281
Introduction to Sensors and Actuators

Diesel Fuel Injectors-Compressor
Solenoid Valves-Transmission Valves

Presented By
Arun Jose
Assistant Professor
Mechatronics

Diesel Fuel Injectors

- The diesel fuel injector is a pressure valve with the capability of dispersing diesel fuel in required specific patterns, depending on the design of the valve nozzle.
- The diesel fuel injector distributes a pressurized fuel within the combustion chamber.
- The injector has to be able to withstand the temperature and pressure inside the cylinder and still deliver the fuel in a fine mist.
- Diesel engines are compression ignition engines that have no spark plugs and the diesel fuel is ignited by extreme heat and pressure.

- This requires a very high compression ratio (16 to 1 or higher) in the cylinders, much h**igher injector operating pressures** (10,340 to 17,240 kPa) to overcome compression pressures in the cylinders
- And also requires **precise injector timing** because diesel engine speed and power are controlled by the amount of fuel injected into the engine rather than airflow.
- Figure 3.51 shows a cross section of a diesel electronic injector. The actuator consists of a coil, an armature, and a magnetic circuit.

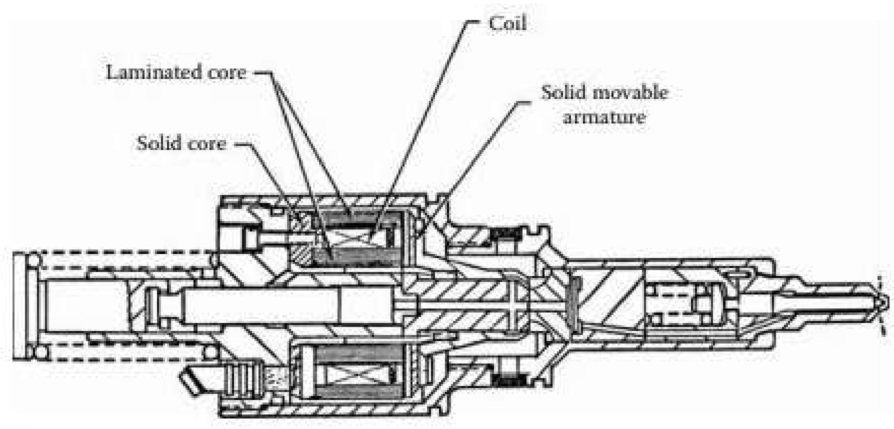


FIGURE 3.51
Electronic diesel injector. (Courtesy of Delphi Corp.)

- The magnetic core has both laminated and solid core parts. Laminated parts are introduced in the form of a wound core to suppress eddy currents and to allow for fast penetration of the magnetic field.

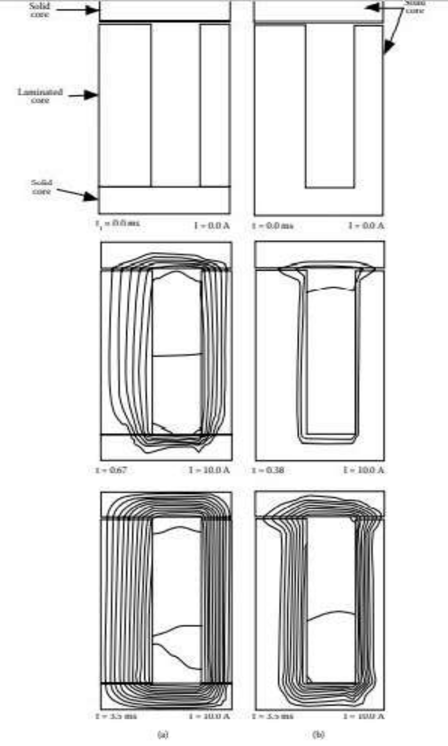
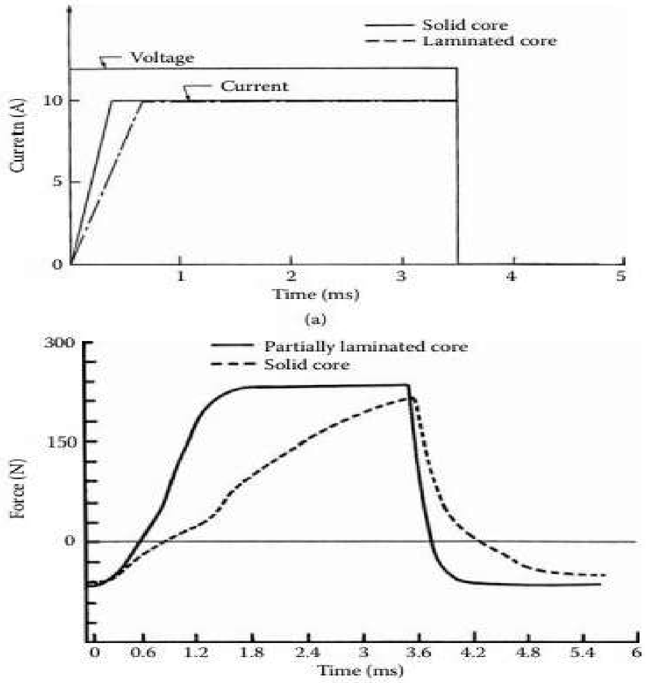


FIGURE 3.52
Flux lines penetration into magnetic core comparison: (a) partially laminated core, (b) solid core. (Courtesy of Delphi Corp.)

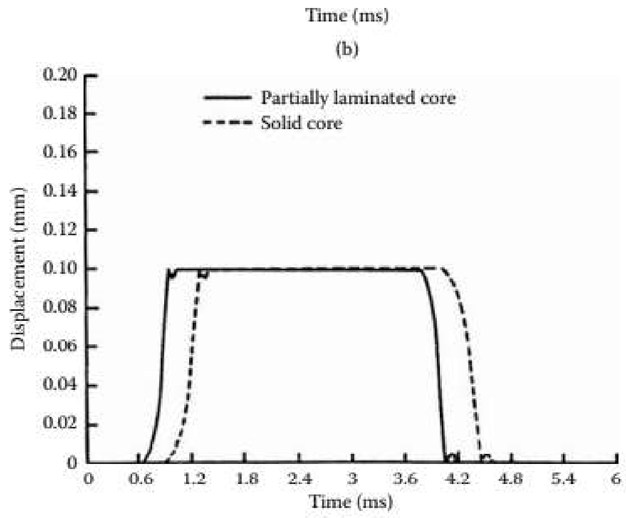
- Figure 3.52 shows a comparison of the penetration of the magnetic field within a laminated and solid core at the same MMF level with a current of 10.0 A.
- Clearly, the magnetic field penetrates much deeper into the laminated core despite the fact that both the bottom and the top (armature) parts are solid.
- Figure 3.53 shows the performance comparison of dynamics between the diesel injectors having partially laminated and solid magnetic cores.

- Figure 3.53(a) shows that the slope of the partially laminated core injector is steeper than the current slope of the injector having a solid core circuit. Because of this, the magnetic force developed by the injector with the partially laminated core is established much faster than the magnetic force of the injector having a solid core circuit ; see Figure 3.53(b)
- Finally, the displacement performance of the armature for the injector with the partially laminated core is superior in comparison with the magnetic force of the injector having the solid core circuit, as presented in Figure 3.53(c).



Compressor Solenoid Valves

- Another application of the solenoid valve is an air-conditioning compressor with variable displacement.
- A unique feature of this compressor is that the displacement can vary depending on the cooling needs by varying the piston stroke.
- Changing the pressure in the crankcase of the compressor modulates the displacement.
- A mechanical valve senses evaporator pressure and bleeds a controlled amount of high-pressure gas into the crankcase.



- The amount of bleed determines the crankcase pressure and the compressor displacement, as presented in Figure 3.57(a)

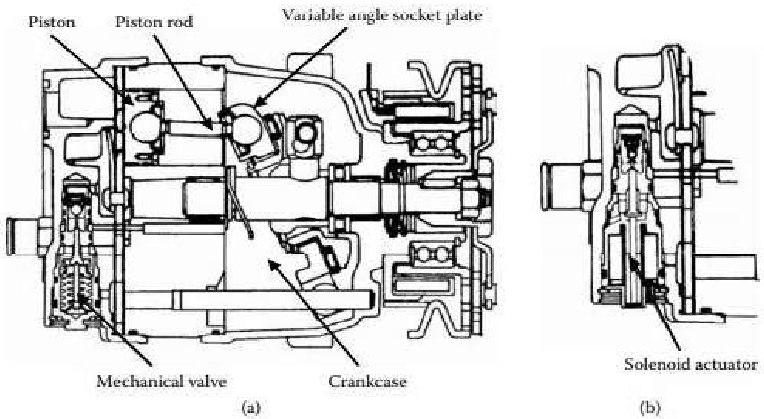


FIGURE 3.57
Cross section of the variable displacement compressor: (a) mechanical pressure control, (b) solenoid pressure control. (Courtesy of Delphi Corp.)

- A solenoid valve replaces the mechanical valve with a plunger-type solenoid actuator, as presented in Figure 3.57(b).
- This permits microprocessor control, resulting in greater flexibility and improved passenger comfort.
- By operating in pulse-width operating mode, the solenoid actuator controls the crankcase pressure between the low-pressure suction gas and high-discharge gas pressure.
- The pressure differential between the top and the bottom of the pistons creates a net force coupled with changes of angle of the socket plate, as presented in Figure 3.57(a). This varies the piston stroke and, thus, the displacement of the compressor.

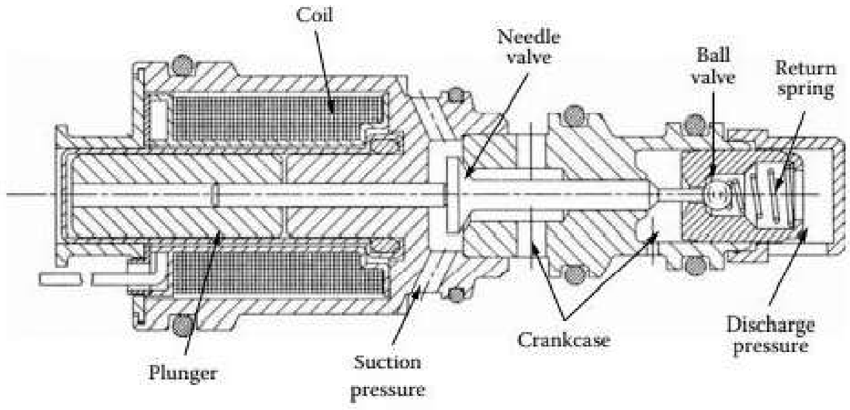


FIGURE 3.58
Solenoid valve actuator. (Courtesy of Delphi Corp.)

- This section describes the results of optimization of the solenoid design.
- In fact, two solenoid designs are obtained: one with maximum plunger force and another with the minimum current draw.
- Maximizing the force at the nominal current should improve valve stability and make performance less sensitive to manufacturing tolerances.
- However, minimizing the current draw at the nominal plunger force should simplify the driver unit and reduce its cost.
- The original design of the solenoid actuator for the compressor is shown in Figure 3.58.

- When the coil is energized, the needle valve closes and a ball valve opens.
- This exposes the crankcase to a high-pressure discharge gas, which increases the crankcase pressure.
- When the coil is not energized, the needle valve opens by the return spring, which vents the compressor crankcase to low-pressure suction gas.
- The solenoid operates at a relatively low frequency of 8.0 Hz or 125.0 ms time period.
- Dynamic operation of the original solenoid takes 6% of the time period and because this is relatively slow, it is acceptable to optimize the static performance of the solenoid.

Transmission Solenoids

- A conventional hydraulic valve body for a hydraulic transmission that used to be specially adapted for each vehicle has been replaced with a microprocessor-based solenoid valve with a controller that permits easier calibration and more precise control of shift.
- In addition, electronic control permits the integration of the engine and transmission computers to optimize powertrain control.
- An important item in developing the electronically controlled transmission is a fast-acting solenoid, as presented in Figure 3.60

- to control clutch pressure by PWM operating a spool valve between a supply and exhaust pressures during shifting with a low current drain from the battery.
- Because there are as many as seven solenoids in a passenger car transmission, three of which are typically on at any one time, even a 1.0 to 2.0 A current drain has a significant impact on fuel economy, alternator size, etc.

- The static performance should be optimized at worst-case operating conditions, a minimum voltage of 9.5 V and an elevated coil temperature of 120.0°C.

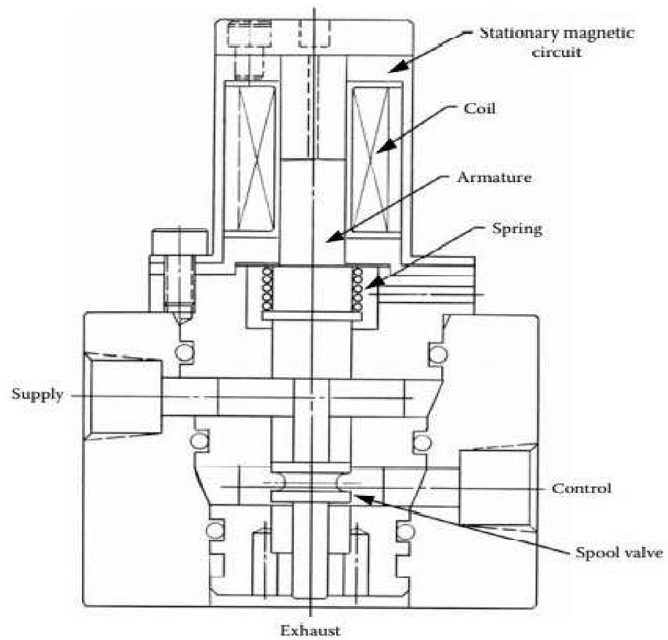


FIGURE 3.60
Transmission spool valve solenoid. (Courtesy of Delphi Corp.)

MODULE 4

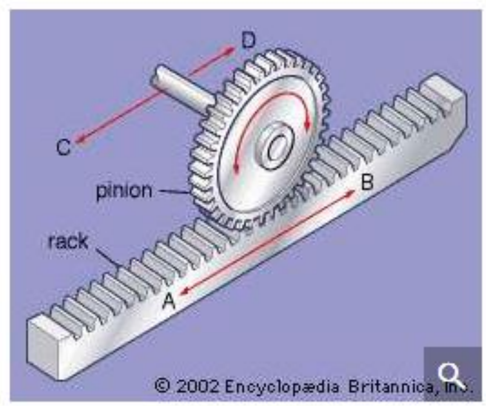
MRT 281

Rotary Actuators –Disk rotary Actuators-Disk Rotary Actuator Designs-Disk Rotary Actuator Excitation Electromagnetic Circuit-Disk Rotary Actuator Tooted Magnetic Part-Disk Rotary Actuator PM

Rotary Actuators

- Rotary actuators are electromagnetic devices developing mechanical torque with limited rotary motion.
- Because of their simplicity and low cost, they are finding more and more industrial applications.
- The demand for rotary actuators is expanding rapidly, particularly in the automotive industry, where they are being used in steering assistance, EGR(exhaust gas recirculation), power door locks, and other applications.
- Some applications are more demanding, requiring an exceptionally high torque level, symmetry, and a stable equilibrium position. In particular, for steering wheel assistance, these requirements would ensure a neutral steering wheel position.

- Three types of rotary actuators are described in this chapter:
- disk actuators with disk magnets having multipole trapezoidal-shaped magnetized poles and axial main air gaps
- claw pole actuators with claw poles and radial air gaps
- cylindrical actuators with rectangular-shaped poles having radial air gaps.
- All these rotary actuators were developed for the automotive application as a major component of the Magnasteer system, which adds an electromagnetic actuator to the conventional hydraulic power steering to provide a variable steering effort function.
- This system consists of an electronic controller and an actuator integrated with the hydraulic power rack and pinion gear in the form of the Magnasteer valve.



Disk Rotary Actuators

- The disk rotary actuator consists of a stationary and a rotary section, as presented in Figure 7.1, which shows rotary and stationary components of the actuator.
- The rotary section consists of a multipole disk PM sandwiched between two mechanically coupled toothed magnetic elements.
- The number of poles of the PM depends on the required angle of limited-angular motion and has double the number of salient teeth of the toothed magnetic-circuit parts.
- The stationary section comprises an external magnetic circuit providing the return path for the magnetic flux produced by the stationary excitation coil.

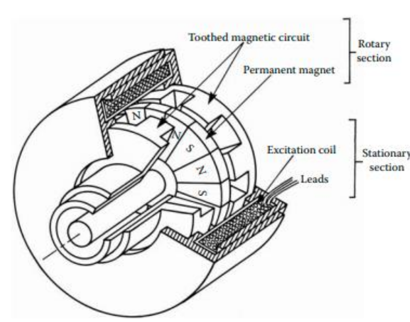
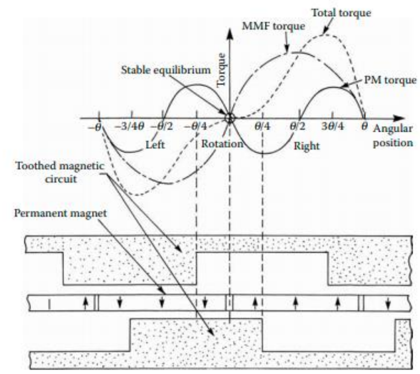


FIGURE 7.1
Disk rotary actuator configuration. (From Pawlak, A.M., *Proceedings of ICEM '90 International Conference on Electrical Machines*, Cambridge, MA, August 13–15, 1990. With permission.)

- The excitation coil is placed on a stationary part and the toothed magnetic parts and PM are part of a rotary section that allows free rotation of the toothed structure.
- In addition to the full rotary motion of the actuator rotary section, this configuration allows for limited angular motion of the PM disk with respect to the toothed magnetic parts.
- This motion is mechanically limited in both the left and right directions of rotation.
- To satisfy the symmetrical torque requirement and provide the stable equilibrium at the neutral PM position, a unique actuator magnetic-circuit configuration was devised.
- A stable equilibrium for both the energized coil MMF and PM was established with a half overlap arrangement, as presented in Figure 7.2, with the magnet located in the middle of this shift.



E 7.2
uilibrium position arrangement. (From Pawlak, A.M., *Proceedings of ICEM '90 Internation* Machines, Cambridge, MA, August 13–15, 1990. With permission.)

- The external magnetic circuit provides the same polarity, depending on the direction of the excitation current, to all the teeth of the toothed magnetic part regardless of its angular position.
- This homopolar actuator configuration enables the reversal of the torque by simply reversing the direction of the excitation current.
- Unlike other electromagnetic devices, the disk rotary actuator utilizes both the external and internal PM surfaces for torque development, thus providing a high-torque density structure.
- Proper balance of both magnetic flux levels (flux densities) — one due to internal PM and the second due to stationary external coil — is the most important task during the actuator's design optimization

Disk Rotary Actuator Design

- With the introduced 2D FE mathematical model, one can design the disk actuator. The design optimization can be pursued by using a parametric study technique.
- If the goal of the actuator design is to maximize its torque (force FT) level for the nominal current excitation, each optimization process should be followed by an iteration of the three-step parametric variations for the excitation coil (wire size, number of turns, resistance), the PM (magnetic material properties, geometry), and the magnetic circuit (geometry of the toothed structure, magnetic-circuit path, and the selected magnetic material properties).

Disk Rotary Actuator Excitation Electromagnetic Circuit

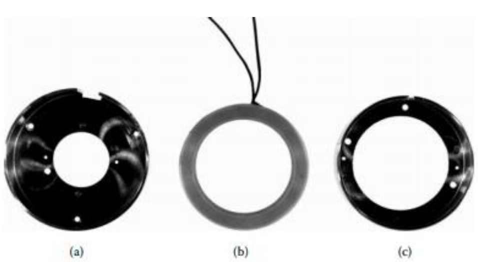


FIGURE 7.9
Disk rotary actuator excitation circuit parts: (a) magnetic housing, (b) coil, (c) magnetic housing. (Courtesy

- This ring-shaped coil is placed in the stationary side of the actuator for ease of excitation without sliding contacts.
- Further, the external location of this electromagnetic circuit is preferable from the heat dissipation point of view, providing an increased cooling surface through the contact with the other assembly parts.
- The magnetic circuit consists of two pressed C-shaped rings, which fit tightly and surround the coil. The lead wires are introduced through a special cut in its external wall.
- The inside walls are not connected to prevent a magnetic-circuit short, and they are adjusted to match the tooth magnetic part thickness to minimize the reluctance of the parasitic air gap between the stationary core and the toothed parts

- **Disk Rotary Actuator Toothed Magnetic Part**

FIGURE 7.10
Disk rotary actuator toothed structure. (Courtesy of Delphi Corp.)

- The reluctance variation introduced by the toothed magnetic parts, as shown in Figure 7.10, plays an important role in the development of the actuator torque.
- **The number of teeth (10 in this case) is determined by the maximum angular position required. The period of torque waveform is inversely proportional to the number of teeth.**
- To achieve a maximum torque with an angular displacement of 4.5°, the desirable period between torque peaks is 9°. This corresponds to 36° pole pitch or 10 teeth, as shown in Figure 7.1.
- **The number of teeth also affects the torque developed by the actuator.**

- The electromagnet magnetic-circuit geometry was determined based on flux saturation levels of the different parts for the selected magnetic material.
- The toothed structure is similar to the VR machines where the ratio of tooth height to its width has to be optimized.

Disk Rotary Actuator PM

- As illustrated in Figure 7.12, the PM has a disk shape with multipole axial magnetization, which shows magnet geometry, magnetization pattern, and magnet hardware model.
- The number of poles was established by the required angle of rotation, and the actuator geometry was determined by the magnet geometry.
- Both magnet thickness and material properties determine the magnet strength

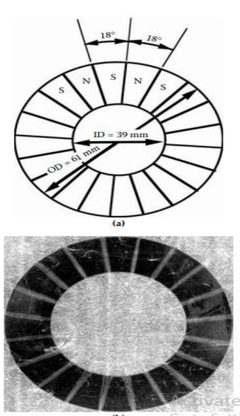


FIGURE 7.12
Disk magnet geometry and magnetization pattern. (a) Magnet geometry, (b) magnetization pattern, (c) magnet model. ([a] From Pawlak, A.M., *Proceedings of the Permanent Magnet Systems Conference*, Atlanta, GA, September 25–27, 2000. With permission; [b] courtesy of Delphi Corp.; [c] from Pawlak, A.M., *Proceedings of IEEE/IAS '95 Conference*, Orlando, FL, October 9–13, 1995. With permission.)

Disk Rotary Actuator Test Results

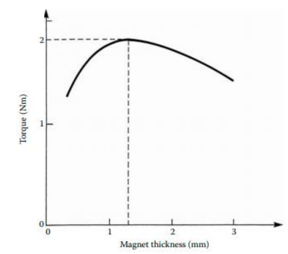
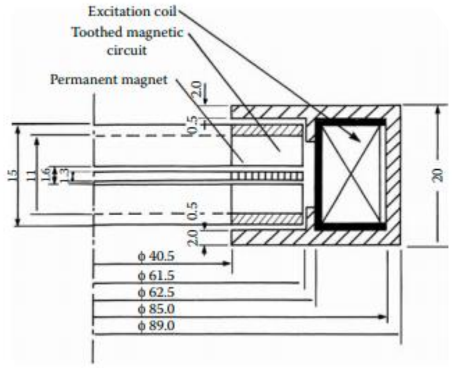


FIGURE 7.14
Torque vs. magnet thickness. (From Pawlak, A.M., *Proceedings of ICEM '90 International Conference on Electrical Machines*, Cambridge, MA, August 13–15, 1990. With permission.)



URE 7.15
rotary actuator geometry. (Courtesy of Delphi Corp.)

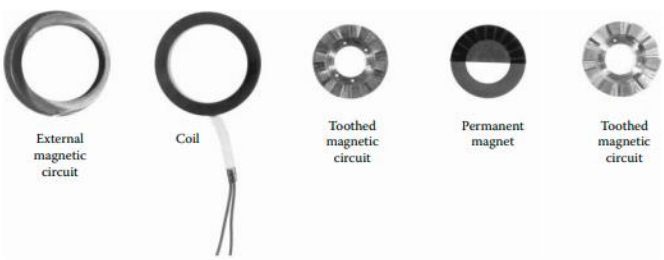


FIGURE 7.16
Disk rotary actuator components. (From Pawlak, A.M., *Proceedings of ICEM '90 International Conference on Electrical Machines*, Cambridge, MA, August 13–15, 1990. With permission.)

FIGURE 7.17
Disk rotary actuator assembly. (From Pawlak, A.M., *Proceedings of ICEM '90 International Conference on Electrical Machines*, Cambridge, MA, August 13–15, 1990. With permission.)

MRT 281 SENSORS AND ACTUATORS

CLAW POLE ROTARY ACTUATOR-CLAW POLE ROTARY ACTUATOR ANALYSIS-CLAW POLE ROTARY ACTUATOR DESIGN-CLAW POLE ROTARY ACTUATOR EXCITATION ELECTROMAGNETIC CIRCUIT-CLAW POLE ACTUATOR TOOTED MAGNETIC PART- CLAW POLE ACTUATOR PM

CLAW POLE ROTARY ACTUATOR

- Claw pole rotary actuators with a multipole ring PM that develop symmetrical limited angular movement electromagnetic torques in both the left and right directions of rotation.
- The complicated 3D geometry of the actuators has a configuration similar to that of claw pole stepper motors.
- These actuators can be used in any application that requires both repulsive and attractive torques over a limited angle of rotary motion.
- Because of their homopolarity, the unlimited rotation of the rotary elements does not affect the rotary actuator capabilities of developing electromagnetic torque.

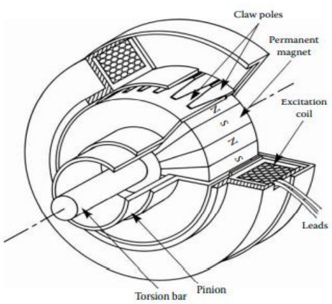


FIGURE 7.20
Claw pole rotary actuator. (From Pawlak, A.M., *Proceedings ICEM '92 International Conference on Electrical Machines*, Vol. 1, University of Manchester Press, 1992. With permission.)

- The claw pole actuator consists of two sections — a rotary and a stationary section — as presented in Figure 7.20
- **The stationary section:** is composed of an electromagnet that consists of a coil and two L-shaped magnetic core parts.
- The stationary location of the excitation coil allows contactless current connections. The external magnetic circuit always provides the same polarity to each claw pole section, regardless of its angular position.
- The specific polarity of the claw pole sections depends on the direction of the excitation current and determines whether the actuator develops attractive or repulsive magnetic spring forces.
- Because of this, such an electromagnetic device has inherent homopolar features, which enable the reversal of torque by simply reversing the excitation current.

- **The rotary section:** comprises a multipole PM ring and a claw pole magnetic core. Both the claw pole structure and the ring magnet have unlimited freedom of movement in the left and right directions of rotation..
- In addition to the full rotary motion of the actuator center parts, this configuration allows for a limited-angular motion of the PM ring with respect to the claw poles as required for the automotive speed-sensitive steering application.
- For this application, two degrees of mechanical freedom are needed: one for rotation of a steering wheel without driver effort, and the second for a limited-angular motion steering assist when the driver applies effort to the steering wheel.

- This motion is mechanically limited for both directions of rotation. Unfortunately, such a mechanical separation, which is necessary to provide unlimited mechanical freedom, introduces additional parasitic air gaps in the magnetic circuit, which adversely affect the magnetic flux level.
- Figure 7.21 shows the distributed view of the claw poles and the corresponding torque profile. The number of poles indicates the period of the actuator torque waveform with respect to the angular position

CLAW POLE ROTARY ACTUATOR APPLICATION

- The claw pole actuator basic geometry for the improved speed-sensitive steering application is shown in Figure 7.60.
- In this arrangement, however, both working areas of the PM and claw poles are limited, because only 79% of the active magnet and claw poles are utilized.
- An improved actuator configuration can be obtained by a special rearrangement wherein the magnet is attached to different assembly components, as shown in Figure 7.61

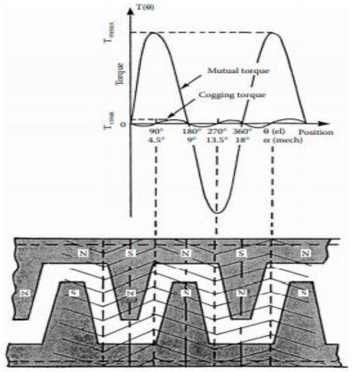


FIGURE 7.21
Claw pole rotary actuator torque vs. displacement. (From Pawlak, A.M., *Proceedings ICEM '92 International Conference on Electrical Machines*, Vol. 1, University of Manchester Press, 1992. With permission.)

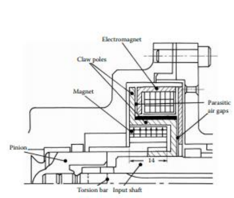


FIGURE 7.60
Base claw pole actuator assembly. (Courtesy of Delphi Corp.)

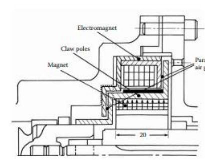


FIGURE 7.61
Improved claw pole actuator assembly. (Courtesy of Delphi Corp.)

- This arrangement fully utilizes the working space under the claw pole structure. The axial length of the PM was increased from 14.0 × 10–3 m to 20.0 × 10–3 m and the effective claw pole length was enlarged from 9.8 × 10–3 m to 20.0 × 10–3 m.
- Because certain measures were taken to decrease the MMF drop at the parasitic air gaps, it was necessary to increase the actuator package by a small volume, as represented by the dotted line in Figure 7.61.
- The thickness of the magnetic circuit is designed to avoid local saturations and, therefore, to enhance the magnetic flux performance.
- The improved torque performance is 60% higher in comparison with the base actuator at the nominal current of 3.0 A and with an angular displacement of 4.5°

- The improved configuration offers higher torque, but requires some additional space which, in this particular application, was not acceptable for the conventional steering gear design for which this actuator was adopted. Side elements are two-component housing for the center claw pole rotary actuator assembly.

CLAW POLE ROTARY ACTUATOR DESIGN

- The final claw pole actuator design was optimized based on the required actuator envelope, temperature, and the nominal current level for the selected magnetic materials

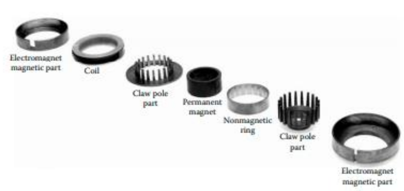


FIGURE 7.23
Distributed view of the claw pole actuator. (From Pawlak, A.M., *Proceedings ICEM '92 International Conference on Electrical Machines*, Vol. 1, University of Manchester Press, 1992. With permission.)

CLAW POLE ROTARY ACTUATOR EXCITATION ELECTROMAGNETIC CIRCUIT

- The excitation **electromagnetic circuit** consists of a **coil** and a **magnetic-circuit core.**
- The coil has 200 turns with wire size 21 AWG. The nominal current of claw pole design is restricted to 3.0 A.
- The ring-shaped electromagnetic excitation circuit is stationary and, therefore, is excited through two leads without slip rings.
- The external location of this electromagnet is preferred for heat transfer reasons because such a location increases the area of heat dissipation through its attachment to the stationary housing

- The magnetic circuit consists of two L-shaped rings that fit tightly and surround the coil, both having a special cut in the external walls to allow for lead passage, as presented in Figure 7.24.

FIGURE 7.24
Claw pole rotary actuator electromagnet parts. (From Pawlak, A.M., *Proceedings ICEM '92 International Conference on Electrical Machines*, Vol. 1, University of Manchester Press, 1992. With permission.)

- The outside walls are adjacent to provide a large cross section for the magnetic circuit. Their height is matched to the claw pole magnetic part thickness to allow for maximum area of the parasitic air gap, thereby minimizing the MMF drop along this gap.
- The claw pole's shape and dimensions play an important role in the development of the electromagnetic torque, and they are related to the magnet pole dimensions. These dimensions were optimized to maximize the torque at the nominal current.

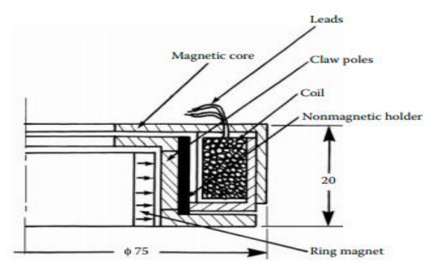


FIGURE 7.25
Claw pole rotary actuator cross section. (Courtesy of Delphi Corp.)

- Figure 7.25 shows a cross section of the actuator parts.
- The magnetic circuit consists of two pressed L-shaped rings that fit tightly and surround the coil with an opening for the leads passage.
- The outside walls are adjacent to provide a bigger cross section for the magnetic circuit and their height is related to the claw pole magnetic part thickness to maximize the flux crossing the parasitic air gap.
- Both sides of the L-shaped parts are enlarged to increase the flux crossing area to the claw pole magnetic parts and to minimize the MMF drop along the parasitic air gap.

CLAW POLE ACTUATOR TOOTED MAGNETIC PART

- Both the geometry (claw pole surface area and mean radius) and the number of teeth affect the total torque level, which is a superposition of the torque developed by each pole-pair section of the actuator. The distributed view of the final claw pole design is shown in Figure 7.26.

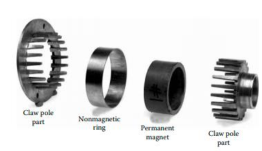


FIGURE 7.26
Claw poles with PM. (From Pawlak, A.M., *Proceedings ICEM '92 International Conference on Electrical Machines*, Vol. 1, University of Manchester Press, 1992. With permission.)

- The shape and dimensions play an important role in the development of the electromagnetic torque and are related to the magnet pole dimensions.
- These dimensions should be optimized to maximize the torque at a given MMF level.
- The number of poles (40) indicates the period of the actuator torque waveform with respect to its angular position.
- Both geometry (claw pole surface area and mean radius) and the number of teeth affect the torque developed by the actuator.

CLAW POLE ACTUATOR PM

- The magnet has multipole arc magnetization with the number of poles equal to the number of claw poles.
- The size and geometry of the ring corresponds to the claw poles.
- The PM is made as one piece and magnetized in a custom-made magnetizing fixture. Figure 7.28 shows the magnet geometry, the magnetic field pattern of the magnetized magnet ring, which is indicated by a magnetic film, and the magnet hardware model.
- The multipole ring PM is located under the claw poles and the number of magnet poles corresponds to the combined number of claws from both claw pole parts. The magnetized ring magnet has a sinusoidal distribution of flux density along its active surface, as shown in Figure 7.29.

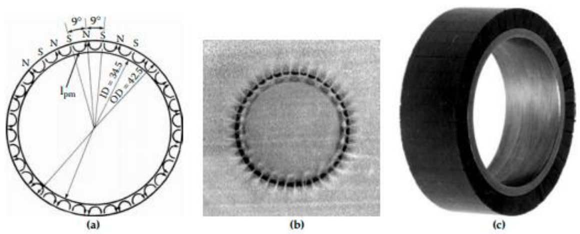


FIGURE 7.28
Ring PM with magnetization pattern. (a) Magnet geometry, (b) magnetization pattern, (c) magnet model. ([a] From Pawlak, A.M., *Proceedings of IEEE/IAS '95 Conference*, Orlando, FL, October 9–13, 1995. With permission; [b] from Pawlak, A.M., *Proceedings ICEM '92 International Conference on Electrical Machines*, Vol. 1, University of Manchester Press, 1992. With permission; [c] courtesy of Delphi Corp.)

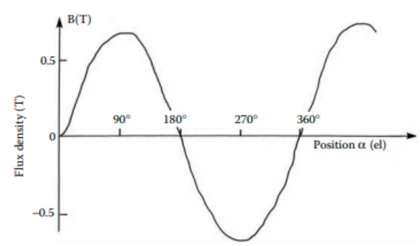


FIGURE 7.29
PM flux-density distribution. (From Pawlak, A.M., *Proceedings ICEM '92 International Conference on Electrical Machines*, Vol. 1, University of Manchester Press, 1992. With permission.)

- Twenty pole pairs (P = 40 poles) were selected for the multipole magnet magnetization to best utilize the relatively small mechanical angle rotation of 4.5°.
- The relation between mechanical and electrical angles of rotation is:
- $\alpha = P\theta/2$
- where θ is a mechanical angle, α is an electrical angle, and P is the number of poles.
- The thickness and material of the PM were selected to provide the field strength necessary to develop the required torque in interaction with the electromagnet.

- Several magnet materials were investigated — Ferrite Ceramic 8, Neo bond 50, and Magnequench MQI
- For the original design the Ferrite Ceramic 8 magnet material was used. Analysis indicated that this design is capable of developing a 0.88 Nm torque at the nominal MMF of 600.0 At and displacement of 4.5°.
- Upgrading the magnet material to Neo bond 50 improved the torque level to 1.38 Nm, which still did not satisfy the requirements.
- By changing the magnet material to MQI, the torque further improved to 1.67 Nm, as shown in Figure 7.30, which satisfied the torque requirements.

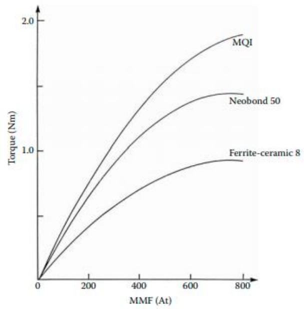


FIGURE 7.30
Torque vs. current analysis. (From Pawlak, A.M., *Proceedings ICEM '92 International Conference on Electrical Machines*, Vol. 1, University of Manchester Press, 1992. With permission.)

MRT 281
SENSORS AND ACTUATORS

Cylindrical Rotary Actuator-Cylindrical Rotary Actuator PM-Cylindrical Rotary Actuator Excitation Electromagnetic Circuit-Cylindrical Rotary Actuator Toothed Magnetic Structure

Cylindrical Rotary Actuator

- This section describes a modern homopolar rotary actuator with a ring radially magnetized multipolar PM featuring a high-force density, transverse flux configuration, which performs a spring action by developing electromagnetic torques with limited-angular movement.
- The rotary actuator investigated features high-performance torque output because the actuator's topology provides a magnetic torque gearing affect
- The torque level is proportional to the number of independent magnetic sections, which are equal to the number of stator teeth or magnet pole pairs. Therefore, the total force developed by the actuator is the sum of the forces developed by each tooth-pitch section .

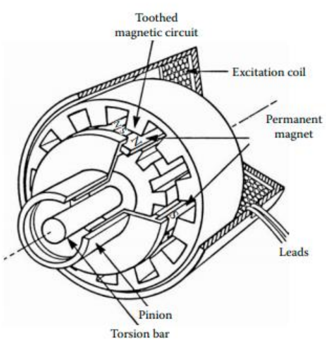


FIGURE 7.34
Cylindrical rotary actuator. (From Pawlak, A.M. et al., *Magnetic Power Steering Assist System — MAGNASTEER*, Publ. No. 940867, Society of Automotive Engineers, Detroit, MI, 1994. With permission.)

- The homopolar rotary actuator consists of three basic components:
- a stationary electromagnet
- a rotary toothed pole structure
- and a rotary multipolar PM ring.

The stationary electromagnet

- is composed of an external magnetic circuit and a precision wound coil fully encapsulated in a plastic molding.
- The stationary coil location enables brushless current connections, essential for reliability.

rotary toothed pole structure

- The toothed pole structure is manufactured as a single piece using advanced powder-metal technology, which allows the two concentric VR ferromagnetic toothed structures to be attached together by a nonmagnetic disk.

multipolar PM ring

- The high-energy neodymium PM ring with energy density of 32 MGOe and multipolar radially oriented magnetization was developed for the purpose of this actuator.
- The PM is located inside the toothed structure with the number of pole pairs corresponding to the number of teeth.

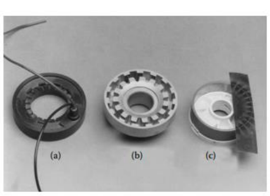


FIGURE 7.35
Cylindrical rotary actuator parts: (a) coil, (b) toothed structure, (c) magnet and magnetization pattern. (Courtesy of Delphi Corp.)

Cylindrical Rotary Actuator Design

- Validation of the 3D FE model, based on both test and analytical results, proved the model to be useful for engineering design purposes. Using this mathematical model, parametric studies were performed to optimize the geometry of the rotary actuator.
- The goal of the actuator design optimization was to maximize the torque developed for nominal coil excitation current.
- The optimization follows an iterative process, with each iteration consisting of a three-step parametric study for the excitation coil (wire size, number of turns,resistance)
- the PM (material magnetic properties, geometry), and the magnetic circuit (geometry of the toothed structure, magnetic-circuit path).

- For the excitation coil, the nominal voltage and the coil size were predetermined by the electronic controller and envelope size specifications.
- the coil MMF was determined from the selected coil parameters, based on the thermal dissipation capacity at a given operating temperature.
- Validation of the 3D FE model based on both test and analytical results proved this model to be useful for engineering design purposes.

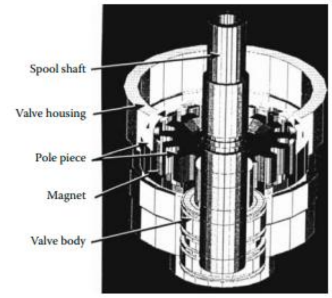


FIGURE 7.42 (Color Figure 7.42 follows p. 294.)
A 3D actuator geometry for the full model. (From Pawlak, A.M. et al., *Proceedings of the IEEE/IAS '94 Conference*, Vol. 1, Denver, CO, October 2–6, 1994. With permission.)

Cylindrical Rotary Actuator PM

- The novel technology of ring neodymium magnets with radial orientation was developed by Hitachi and Daido of Japan in the early 1990s for the cylindrical rotary actuators for the Magnasteer system.
- Hitachi mastered the sintered method while Daido utilized the plastic flow of the neodymium magnets for the back extrusion method.
- Figure 7.48 shows radially oriented ring magnet geometry, multipole magnetization pattern, and magnet final model structure.
- This magnet is the world's first successful development of high-energy radially oriented ring magnet applied for mass production.

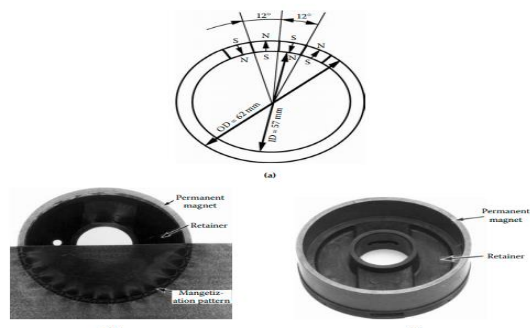


FIGURE 7.48
Ring neodymium magnet with radial orientation. (a) Magnet geometry, (b) magnetization pattern, (c) magnet model. ([a] Courtesy of Delphi Corp.; [b] from Pawlak, A.M. et al., *Magnetic Power Steering Assist System — MAGNASTEER*, Publ. No. 940867, Society of Automotive Engineers, Detroit, MI, 1994. With permission; [c] from Pawlak, A.M., *Proceedings of the Permanent Magnet Systems Conference*, Atlanta, GA, September 25–27, 2000. With permission.)

- PM parameters were established based on actuator requirements and constraints.
- The number of poles (30), equal to the number of teeth and slots, was determined by the required angle of rotation, and the actuator geometry was determined by the specified envelope size.
- The ring PM with multipole radial magnetization is inserted between two magnetic pole pieces and, **similar to disk configuration**, the number of magnetic poles is equal to double the number of magnetic poles and the magnetic poles are shifted by half of the pole pitch to provide an additional stable equilibrium position of the magnet.
- Similar to the disk actuator with the coil excitation, all poles on one side of the cylindrical actuator assume the same polarization, which is different for each side acting as a homopolar structure.

- The PM is made as one piece and magnetized in a custom-made magnetizing fixture to secure both the required magnetic field shape and required neutral zone to secure a stable equilibrium position of the rotor.
- The thickness of the PM is an additional air gap added to the main air gaps for the magnetic flux developed by the excitation coil. Such a large total air gap adversely affects the magnetic flux level in the main air gaps, thus affecting the force developed.
- Based on the magnet thickness parametric study conducted for the three different MMF levels, the thickness of 2.5 × 10–3 m was selected, as shown in Figure 7.49

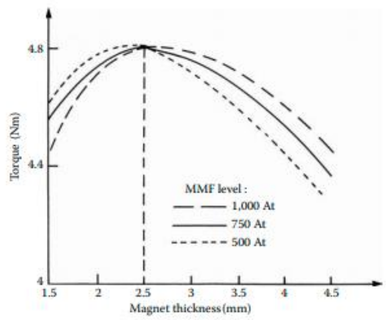


FIGURE 7.49
Magnet thickness study. (From Pawlak, A.M. et al., *Proceedings of the IEEE/IAS '94 Conference*, Vol. 1, Denver, CO, October 2–6, 1994. With permission.)

Cylindrical Rotary Actuator Excitation Electromagnetic Circuit

- The coil is also manufactured using advanced precision winding technology and is overmolded with plastic.
- For the overmolding process, a golf ball technique was utilized to secure perfect sealability of the plastic around the coil.
- This is important to prevent a potential leak problem because the coil is submerged in the steering fluid all the time.

Cylindrical Rotary Actuator Toothed Magnetic Structure

- The reluctance variation introduced by the toothed magnetic structure, shown in Figure 7.55, plays an important role in the development of the actuator torque.
- Tooth and slot dimensions are related to the magnet pole dimensions.
- These dimensions were optimized to maximize torque at a given MMF level. The number of teeth (15) indicates the number of independent magnetic sections that develop electromagnetic torque.
- . Both the geometry and the number of teeth affect the torque developed by the actuator, which is a superposition of the torque developed by each pole pair for the actuator with cylindrical symmetry.
- They also indicate the period of the actuator torque waveform with respect to the angular position

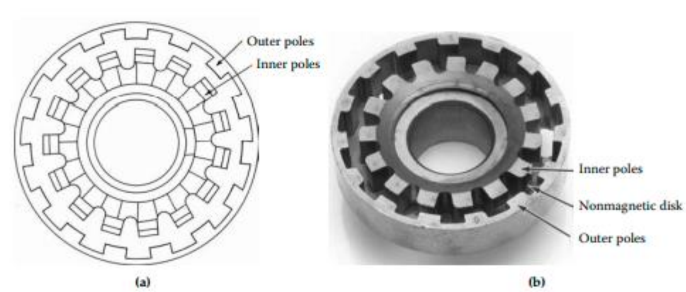


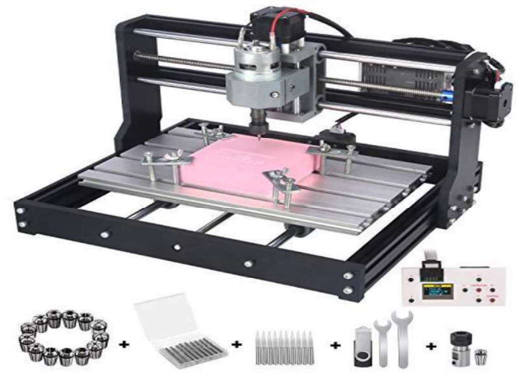
FIGURE 7.55
Pole piece toothed structure: (a) toothed structure geometry, (b) toothed magnetic structure. ([a] Courtesy of Delphi Corp.; [b] from Pawlak, A.M. et al., *Magnetic Power Steering Assist System — MAGNASTEER*, Publ. No. 940867, Society of Automotive Engineers, Detroit, MI, 1994. With permission.)

- Low-cost, high-density powder-metal technology was used in the manufacturing of the magnetic toothed structure.
- Both the external and internal teeth are made out of magnetic powder, and the connecting plate is made of nonmagnetic stainless steel powder.
- All three parts are made in one pressing process, thus reducing the number of parts and improving manufacturing precision. This is the world’s first part made as a solid piece out of both magnetic and nonmagnetic powder metal. Figure 7.55 shows the final magnetic tooth shape and elements.

MODULE 5

MRT 281 SAS

CONTROL OF NC MACHINES AND FLUDIC CONTROL-STEPPING MOTORS-FEEDACK DEVICE-ENCODERS-RESOLVERS-INDUCTOSYNC-THACHOGENARATORS



FUNDAMENTALSOF NUMERICAL CONTROL

- Controlling a machine tool by means of a prepared program is known as numerical control, or NC
- NC equipment has been defined as “A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data.“
- a typical NC system the numerical data which is required for producing a part is maintained on a punched tape and is called the part program.
- The part program is ranged in the form of blocks of information, where each block contains the numerical data required to produce one segment of the workpiece.

- The punched tape is moved forward by one block each time the cutting of a segment is completed.
- The block contains, the coded form, all the information needed for processing a segment of the workpiece: the segment length, its cutting speed, feed, etc
- Compared with a conventional machine tool, the NC system replaces the manual actions of the operator.
- In conventional machining a part is produced by moving a cutting tool along a workpiece by means of hand wheels, which are guided by an operator.
- Contour cuttings are performed by an expert operator by sight.
- On the other hand, operators of NC machine tools need not be skilled machinists.

- They only have to monitor the operation of the machine, operate the tape reader, and usually replace the workpiece.

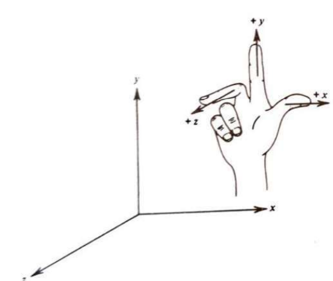


Figure 1-1 A right-hand coordinate system.

Open-Loop and Closed-Loop Systems

- Every control system, including NC systems, may be designed as an open- or a closed-loop control.
- The term open-loop control means that there is no feedback, and the action of the controller has no information about the effect of the signals that it produces .
- The open-loop NC systems are of digital type and use stepping motors for driving the slides (A stepping motor is a device whose output shaft rotates through a fixed angle in response to an input pulse)
- The stepping motors are the simplest way for converting electrical pulses into proportional movement, and they provide a relatively cheap solution to the control problem

DRIVES

- Drives for NC and robot systems are either **hydraulic actuators, dc motors, or stepping motors**. The type selected is determined by the power requirements of the machine tool, the power sources available, and the desired dynamic characteristics.
- **Stepping motors** are limited in power and available torque, and thus suitable only for small machine tools.

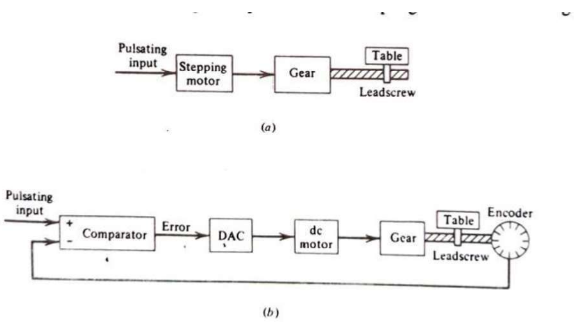
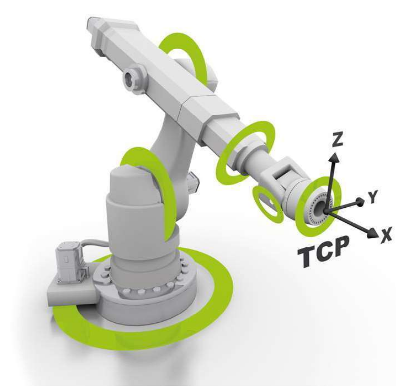


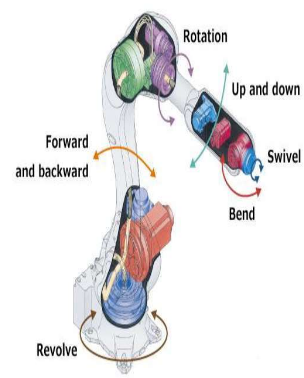
Figure 1-8 Open-loop (*a*) and closed-loop (*b*) digital control.

DC motors

- DC motors provide excellent speed regulation, high torque, and high efficiency, and therefore they are ideally suited for control applications.
- DC motors can be designed to meet a wide range of power requirements and are utilized in most small- to medium-sized robots and NC machines.

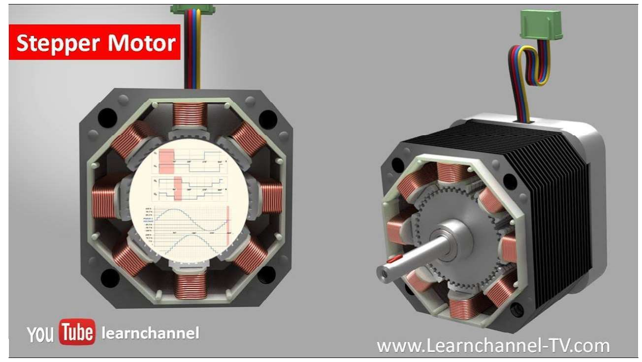
- Since there is no feedback from the slide position, the system accuracy is solely a function of the motor's ability to step through the exact number of steps which is provided at its input.
- The closed-loop control measures the actual position and velocity of the axis and compares them with the desired references.
- The difference between the actual and the desired values is the error.
- The control is designed in such a way as to eliminate, or reduce, to a minimum, the error, namely the system is of a negative-feedback type.
- CNC MACHINE- computer numerical control –**CNC machines** are **machine** tools that cut or move material as programmed on the controller
- ROBOT SYSTEM





Hydraulic systems

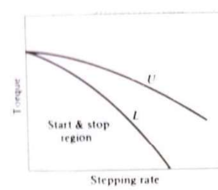
- Hydraulic systems can range in size up to hundreds of horse powers.
- They are well suited for large robots and NCC machine tools where power requirements are high.
- The cost of a hydraulic drive is not proportional to the power required, and, thus, they are expensive for small- to medium- Sized robots and NC machines.



Stepping motors

- **Stepping motors** are limited in power and available torque, and thus suitable only for small machine tools.
- The stepping motor (SM) is an incremental digital drive.
- It translates an input pulse sequence into a proportional angular movement and rotates one angular increment, or a step, for each input pulse.
- The shaft position is determined by the number of pulses, and its speed is proportional to the pulse frequency. The shaft speed in steps per second Is cqual to the input frequency in pulses per second (pps)

- incoming pulses into the correct witching sequence required to step the motor.
- The steered pulses are converted to power pulses, with appropriate rise time, duration, and amplitude for driving the motor windings To reverse the motion, an additional input is provided.
- A 0 logic level at the latter causes a clockwise rotation and a 1 logic level-a counterclockwise rotation.



- Stepping Motors can be used as the drive devices in Open-loop NC systems) Since au feedback element is required, the system is cheaper than its closed-loop counterpart.
- However, the accuracy of the system depends upon the motor's ability to step through the exact Number of pulses sent to its input.
- In addition, stepping motors are Limited in torque and tend to be noisy and, therefore, are seldom used in practice.
- To obtain optimal stepping motor performance, an electronic switch, or translator, is required as part of the drive unit.
- The drive unit contains a steering circuit and power amplifier. The steering unit translates the incoming pulses into the correct witching sequence required to step the motor.

- The torque always decreases with an increase in the stepping rate.
- The exact shape of the curves depends on the driving unit and the stepping motor itself.
- The characteristic comprises two curves: the lower L and he upper U, sometimes denoted as the pull-in and pull-out curves, respectively.
- The upper curve shows the maximum running speed and the lower curve shows the maximum allowable starting speed pf the motor

FEEDBACK DEVICES

- in a closed-loop system, information about the output is feedback for comparison with the input.
- Thus, feedback is required to close the loop.
- Feedback elements in the robot systems are usually rotary devices which are directly coupled to the machine leadscrews, and the robot axes, and provide position and velocity signals.
- **Encoders**
- **Resolvers**
- **The inductosyn**
- **Tachometer.**

- When the disk rotates, light is periodically permitted to fall on the photocell, which consequently produces a sinusoidal output Signal in the millivolt range.
- This signal is amplified and fed to a Schmitt-trigger Circuit, which converts it to a square wave with suitable rise and fall times .
- The direction of rotation may be sensed by using an encoder with two photocells Reading the same disk.
- The photocells are arranged so that their outputs have a 90° shift o each other, as shown in Fig. 4-7.
- The direction of rotation can be determined by external logic circuitry, fed by these two sequences of pulses

Encoders

- **An incremental rotary encoder** is one of the most commonly used feedback devices in robot and NC systems.
- The rotary encoder is a shaft-driven device delivering electrical pulse at its output terminals.
- The pulse frequency is directly proportional to the shaft speed. The encoder contains a glass disk mounted on the shaft and marked with a precise circular pattern of alternating clear and opaque segments on its periphery, as is shown in Fig. 4-6.
- A fixed source of light is provided on one side of the disk, and a photocell is placed on its other side.

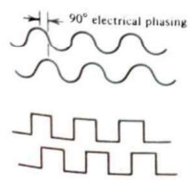


Figure 4-7 (*a*) Phase-shifted output produced by a two-channel encoder; (*b*) square-wave outputs are achieved by applying a Schmitt-trigger shaper.

- An additional index pulse can be available when a separate zone containing only a single clear section is provided in the disk.
- The index pulse can serve as a zero reference position, and is very useful

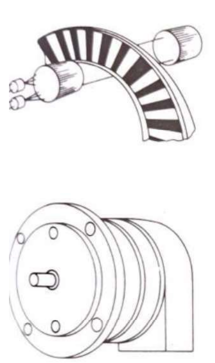


Figure 4-6 Incremental encoder with two-channel output.

- The main disadvantage of **increment type encoders** are the possibility of incorrect data resulting from false counts being generated by noise transients or other outside disturbances.
- It can be reduced by using **absolute encoders.**

Absolute encoders.

- Those errors are eliminated by using absolute encoders. Absolute rotary encoders are using a multiple-track disk which defines the shaft position by means of a binary word or another code. such as the Gray code.
- The reading system employs a lamp and photocells to detect the light which passes through the transparent portions of the disk.
- A photocell is provided for each track on the disk. The output from all cells gives the actual shaft position in coded form.

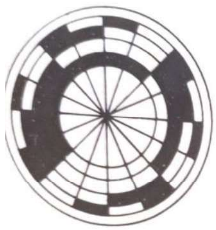


Figure 4-8 Binary code disk of absolute encoder.

$$v_1(t) = V \cos \omega t \quad (4\text{-}19a)$$

$$v_2(t) = V \sin \omega t \quad (4\text{-}19b)$$

The rotor outputs consist of two components

$$v_a = v_1 \sin \phi + v_2 \cos \phi \quad (4\text{-}20a)$$

$$v_b = v_1 \cos \phi - v_2 \sin \phi \quad (4\text{-}20b)$$

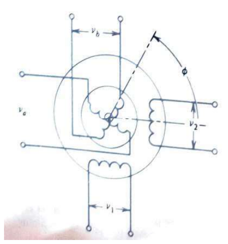
Substituting Eqs. (4-19) into Eqs. (4-20) yields

$$v_a = V \sin (\omega t + \phi) \quad (4\text{-}21a)$$

$$v_b = V \cos (\omega t + \phi) \quad (4\text{-}21b)$$

Resolvers

- Resolvers have the same general construction of a features as small ac motors The rotor and a stator, both having two windings at 90 to one another, as illustrated on in Fig

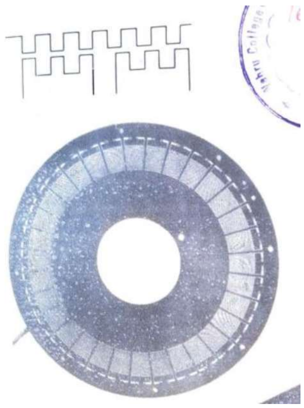


- In NC applications only one of the rotor windings is used, and it produces the feedback signal Va .
- The phase angle, which is contained in the feedback signal, depends on the angular position of the rotor shaft.
- Note that if the rotor is rotated 90°, for example, the phase shift of the rotor winding output voltage is 90° from the reference.

- If an ac voltage is applied to one of the stator coils, a maximum voltage will appear at a rotor coil when those two coils are in line, and the voltage will be zero for at 90 degree.
- As the shaft is turned, the voltage induced in one rotor coil follows a sine wave and the voltage induced in the other follows a cosine wave.
- Similarly, the ac voltage Can be applied to one of the rotor coils, resulting in a sine and cosine of the angular position of the rotor at the two stator winding outputs.
- In NC systems the resolver is used as a shaft position measuring device and is directly coupled to the leadscrew of the machine tool.
- The two windings of the stator are excited by sinusoidal signals equal in frequency and amplitude, but displaced by 90° from each other.

The Inductosyn

- The Inductosyn is a precision measuring device developed by the Farrand Controls.
- Its Principle of operation is similar to that of a resolver with a very large number of stator poles P (e.g., P = 144), rather than two, and with only one rotor coil.
- When a single-phase ac voltage is applied to the rotor windings of a resolver, the voltage output from the two-phase stator windings is proportional to the sine and cosine of the angular position of the rotor relative to the stator as shown in Fig. 4-10a.



Tachometers

- In order to obtain a precise control of the servomotor speed, the actual speed must be measured and compared with the required one.
- The actual speed may be measured in terms of voltage by a small PM dc generator, or tachometer, coupled to the motor shaft.
- The difference between a command voltage proportional to the desired speed and the tachometer voltage may be used to actuate the motor in such a way as to tend t eliminate the error. Negative-feedback closed-loop control is thereby achieved.

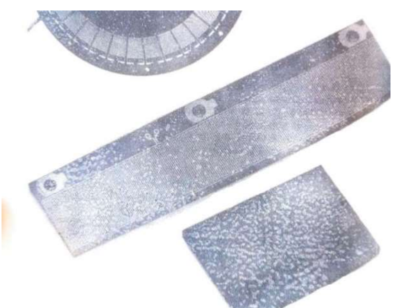


Figure 4-10 (a) Two windings, phase shifted by 90° produce two sinusoidal waves in inductosyn, stator of rotary inductosyn, (c) stator (scale) and rotor (slider) of linear inductosyn. (Courtesy of Farr Controls.)

The output voltage V_p of the dc tachometer is given by Eq. (4-4):

$$V_p = K_p\omega \quad (4\text{-}25)$$

where K_p is the tachometer constant, which is mainly dependent on the magnetic strength of the permanent magnet. In practice the tachometer voltage is fed back through an operational amplifier, which enables the adjustment of K_p.

A simple control loop containing a dc servomotor, amplifier, and tachometer is shown in Fig. 4-11. This loop is referred to as the machine drive unit and is contained

- When the stator windings of an inductosyn transducer are excited by constant amplitude carriers in 90° phase shift, the resulting output signal is a constant amplitude signal that undergoes a continuous phase shift of 360" for each displacement of one cycle length.
- The constant amplitude signal is easily converted to square wave form use in NC applications.
- In the rotary inductosyn the rotor is directly mounted on the leadscrew.
- In the linear form the stator is fixed to the bed of the machine tool, and the rotor to the table; thus the rotor moves parallel to the stator.
- The output from the rotor is fed into an input of a phase detector and compared with one of the stator voltages. T
- he resulting error signal from the phase detector is applied to the machine drive and provides the required movement of the machine table.

- simple control loop containing a dc servomotor, amplifier, and tachometer shown in Fig. 4-11. This loop is referred to as the machine drive unit and is contained

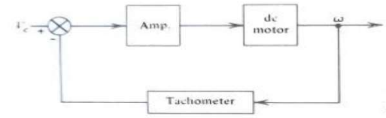


Figure 4-11 Typical machine drive unit

in the position control of each axis of contouring systems. The difference between the command voltage V_c and the tachometer voltage is the error signal e:

$$e = V_c - V_p \quad (4\text{-}26)$$

This error signal is fed to the power amplifier, which produces a voltage V:

$$V = K_a e \quad (4\text{-}27)$$

MRT 281
SAS

Fluidic Sensors-Back pressure Sensor-Cone jet Proximity Sensor –Interruptible Jet Sensor

- **Disadvantage**
- Its main disadvantage is that atmospheric air is entrained in the receiver and if contaminated, can interfere with the performance.
- The limitation can be overcome by lightly pressurising the receiver in the opposite direction (Figure 2).
- The main jet then impinges on the secondary jet, applying back pressure which increases the receiver pressure.
- An object interfering with the main jet cuts off this back pressure and the receiver pressure falls back to its normal level.
- Under both conditions there is always outflow from the receiver which cannot therefore entrain

Interruptible Jet Sensor

- The most common form of pneumatic sensor is the interruptible jet Sensor.

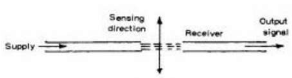


FIGURE 1

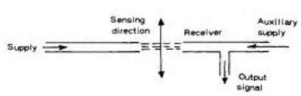


FIGURE 2

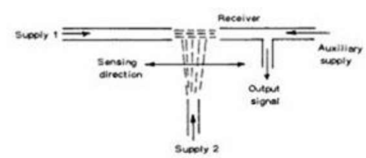


FIGURE 3

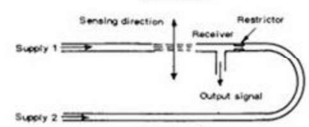


FIGURE 4

- Supply and receiver pipes are aligned axially, separated by a gap.
- The intrusion of any solid object into the gap, interrupting the jet, causes the pressure in the receiver to fall to atmospheric.
- This change in pressure is used to operate a switching element controlling an appropriate circuit, for example a counting circuit.
- The switching element is normally a transducer giving an electric signal output.

Advantage

- This type of sensor has the advantage that it is not critical on gap dimensions, can change its state rapidly for counting purposes and is not sensitive to shape or texture.

- Both of these types require small nozzle sizes in the supply to achieve laminar flow. The effective gap length is the distance over which the laminar flow can be maintained.
- An alternative shown in Figure 3 uses a third jet placed at right angles to the main supply jet.
- The receiver may or may not be pressurized. This works on the principle of a turbulence amplifier, with the main jet flow, normally laminar, being rendered turbulent by the impingement of the side jet, reverting to laminar flow when the side jet is interrupted.
- The practical measuring gap, which is between the side jet and the main jet can be made much larger for the same pressure difference in the receiver.

- A more practical form of interrupted sensor with back flow from the receiver is shown in Figure 4, back flow being obtained from the same supply but with pressure reduced by a restrictor.
- Sensors of this type can be expected to have a maximum gap of about 20 mm working off a supply pressure of about 0.1 bar.

Back pressure sensors

- Back pressure sensors are effective when the object to be sensed can pass close to the jet.
- A single jet is used in this case, the presence of an object modulating the flow and causing a pressure change at the output (Figure 6).
- It can be used to measure objects moving towards or away from it as well as across it, with suitable signal amplification.

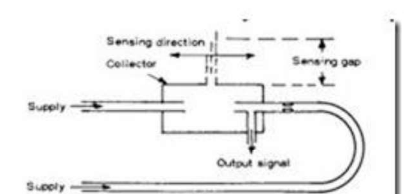


FIGURE 5

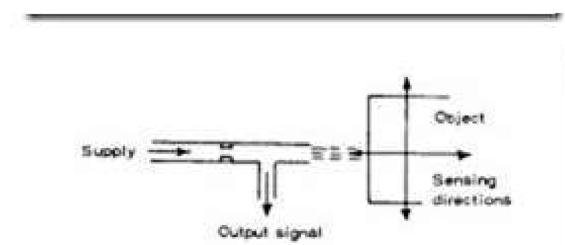
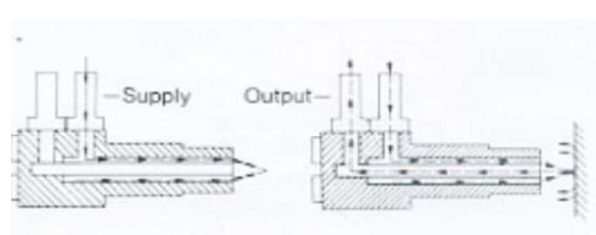


FIGURE 6

- The system shown in Figure 5 is capable of working with larger gaps at the same pressure levels.
- Here a collector is incorporated to supply a second external gap (the sensing gap), with output signal derived from the same position as before. This device is known as an airstream detector.

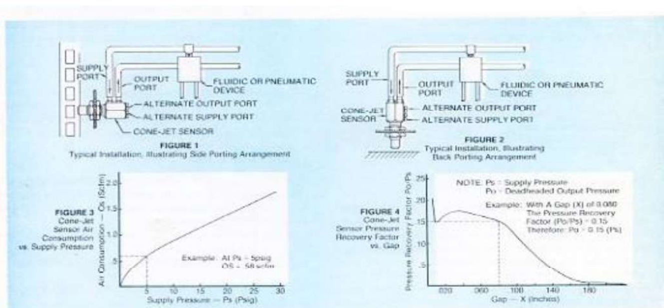
Cone-Jet Proximity Sensor



- The cone jet proximity sensor is a non moving-part device which permits sensing the presence of object with out physical contact.
- It allows as much as 10 times the sensing gap provide by a normal back pressure sensor with far less flow consumption.
- Operation is based on the increases in pressure with in a converging conical flow pattern when resistance to that flow is created by presence of an object or a opposing stream.
- The resulting pressure rise is recovered through the center tube and output port .
- It is operate able on all gases.
- Operating characteristics are compatible with fluids and conventional pneumatic logic and interface devices.

- **<u>Applications</u>**
- the cone jet can sense with out contact, the presence or absence of a physical body or liquid surface regardless of the material composition
- This Unique makes its an ideal device for sensing.

1) Non magnetic bodies such as chrome, paper boxes, and wood
2) Optically transparent bodies such as glass and clear plastic
3) non- rigid materials such as cloth and mesh
4) Liquid level surfaces
5) Surface that cannot be touched



MRT 281

Principle of Fluidic Logic Control- Coanda effect-Basic Fluidic Devices- Fluidic Logic Gates- Bistableflipflops -OR and NOR Gates- Exclusive OR gate

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- Fluidic devices are used in industrial automatic control systems to perfo rm various logic functions and in systems that include digital counters, s hift registers, and units for the bit-by bit comparison of numbers.
- Such devices are used to perform not only discrete operations, such as summing of signals and bit-by bit comparison of codes, but also analog operations, such as conversion , amplification, and frequency modulation of signals.

Principle of Fluidic Logic Control-

- Fluidics,a branch of pneumatic automation that deals with the study, development, and use of devices (elements) that operate on the basis of aerohydrodynamic effects, such as
- momentum interaction
- wall attachment (or wall reattachment)
- creation of turbulence of the stream in a laminar jet
- throttling of flows
- vortex generation.

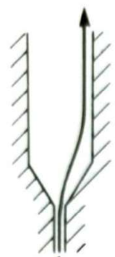
Sequencing Operation

- Process control pneumatics is also concerned with sequencing ie, performing simple actions which follow each other in a simple order or with an order determined by sensors.
- Electrical equivalent circuits are formed with relays, solid state logic or programmable controllers.
- Logic devices (AND, OR gates and memories) are part of the electrical tool kit for sequencing applications.
- The pneumatic equivalent uses the wall attachment or Coanda effect A fluid stream exiting from a jet with a Reynolds number in excess of 1500 (giving very turbulent flow) tends to attach itself to a wall and remain there until disturbed.

- In **discrete momentum-** Interaction elements, the jets flowing out of the input channels deflect other jets coming from the supply channel or from other input channels.
- in this case the pressure and delivery of air at the output of the element vary a ccording to the relay characteristic.
- **In wall-attachment elements**, the properties of boundary layer flows are used to produce and signal storage.
- In **turbulence elements** a relay characteristic is produced by the transition fro m laminar to turbulent flow. Various aerohydrodynamic effects are used in cont inuous operation fluidic elements .

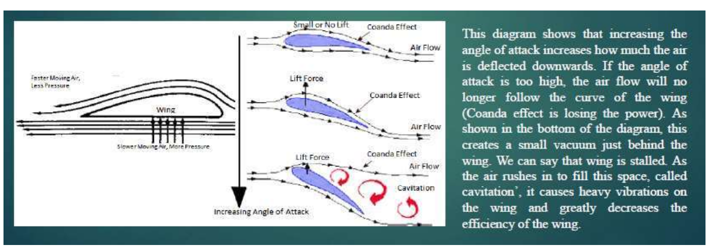
Coanda Effect

- Coanda Effect is the phenomena in which a jet flow attaches itself to a near by surface and remains attached even when the surface curves away from the initial jet direction.
- In free surroundings, a jet of fluid entrains and mixes with its surroundings as it flows away from a nozzle.
- Coanda Effect:
- A moving stream of fluid in contact with a curved surface will tend to follow the curvature of the surface rather than continue traveling in a straight line.



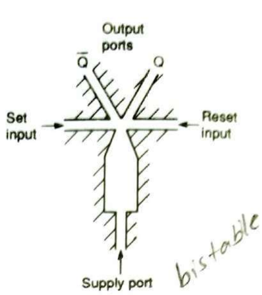
(a) The Coanda effect

- Flip- flop is a different kind of logic circuit is an element capable of storing or memorizing information.
- In memory circuits, the output depends not only on the present level of inputs, but also on the past, or prior, sequence of inputs.
- The logic state of these circuits is changed by pulses, rather than by logic levels as in gates.
- A pulse is characterized by a temporary change in the logic level for a short period of time.
- The basic memory circuit is the flip-flop (FF), which is a binary storage device that has two distinct stable states, and it remains in one of them until it is directed to change it.



- The change between the two states is done by means of two inputs, termed set and reset.
- Whenever a bit of 1 logic level is stored, the device is said to be set. The operation which stores a 0 bit in a flip-flop is called the reset, or clear, operation, and the flip-flop is said to be in the reset state.
- For sensing the state, the flip-flop is provided with two outputs Q and Q'. When Q is at 1 logic level, 0' is at 0, and vice versa.
- This principle is used to give a pneumatic set/reset (S-R) flip-flop memory in If the set input is pulsed, the flow attaches itself to the right-hand wall, exiting via output Q.
- It the set input is then removed the Coanda effect keeps the flow on this route until the reset input is pulsed.

Bistable flip-flops



(b) Set/reset flip-flop

- Flip-flops are the basic elements of registers and counters which are used in NC systems.
- Registers consist of groups of identical flip-flops and are used to store binary information. For example, the binary number 1001 can be represented by a setup of 4 flip-flops, which is termed a 4-bit register.
- A 4-bit register can store a maximum different binary words in NC

fluidic devices

- In a fluidic device a jet of fluid can be deflected by a weaker jet striking it at the side. This provides non-linear amplification, similar to the transistor used in electronic digital logic.
- It is used mostly in environments where electronic digital logic would be unreliable .

Fluidic Triode

- The fluidic triode is an amplification device that uses a fluid to convey the signal.

Fluidic Amplifier

- The basic concept of the fluidic amplifier is described through a patented device as in Fig.- 1. A fluid supply, which may be air, water, or hydraulic fluid, enters at the bottom.
- Pressure applied to the control ports C1 or C2 deflects the stream, so that it exits via either port O1 or O2.
- The stream entering the control ports may be much weaker than the stream being deflected, so the device has gain

Logic Elements

- Fluidic logic (fluidics) uses specially designed fluid paths to perform logic operations, such as AND, OR, and NOT gates.
- In electronics logical operations underpin all the digital devices that depend on CPUs for their brains. Using Computational Fluid Dynamics (CFD) we can quickly explore potential fluidic components.

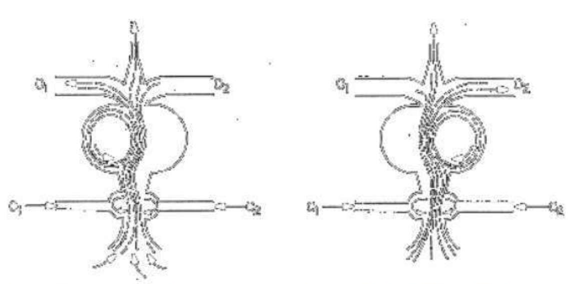
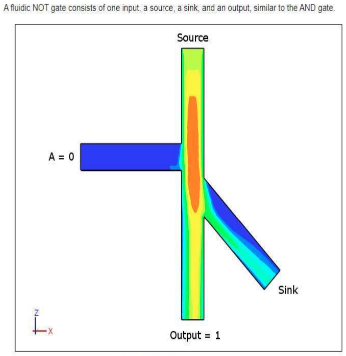
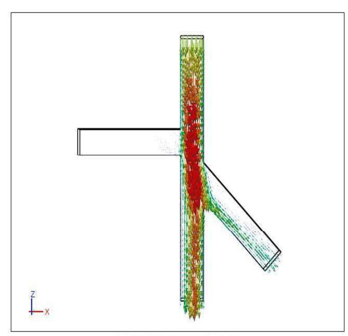


Fig.- 1 Fluidic amplifier, showing flow in both states. Ref: U.S. Patent #4,000,757.

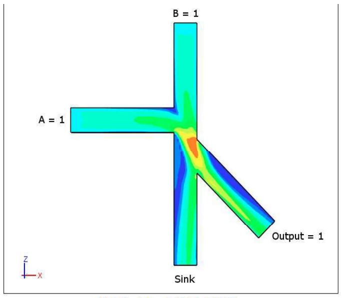
A fluidic NOT gate consists of one input, a source, a sink, and an output, similar to the AND gate.



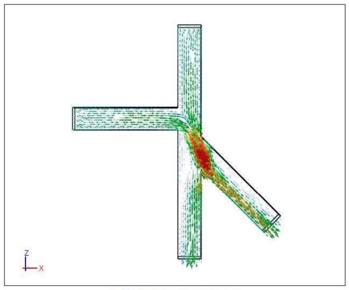
Fluidic NOT Gate: Velocity Magnitude



Fluidic NOT Gate: Velocity Vectors



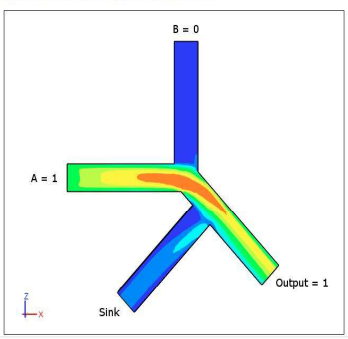
CFD Simulation of a Fluidic AND Gate

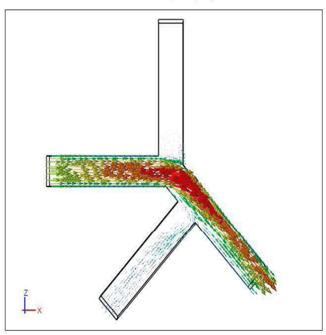


Fluidic AND Gate: Velocity Vectors

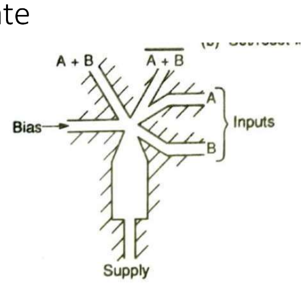
- A small bias pressure Keeps the signal on the right-hand wall, which causes it to exit via the right-hand port. If signal A or B is applied (at higher pressure than the bias) the flow switches over to the (A+ B) output.
- When both A and B signals are removed, the bias pressure switches the flow back again.

A fluidic OR gate consists of two inputs, a sink, and an output.





OR/NOR gate



(c) OR/NOR gate

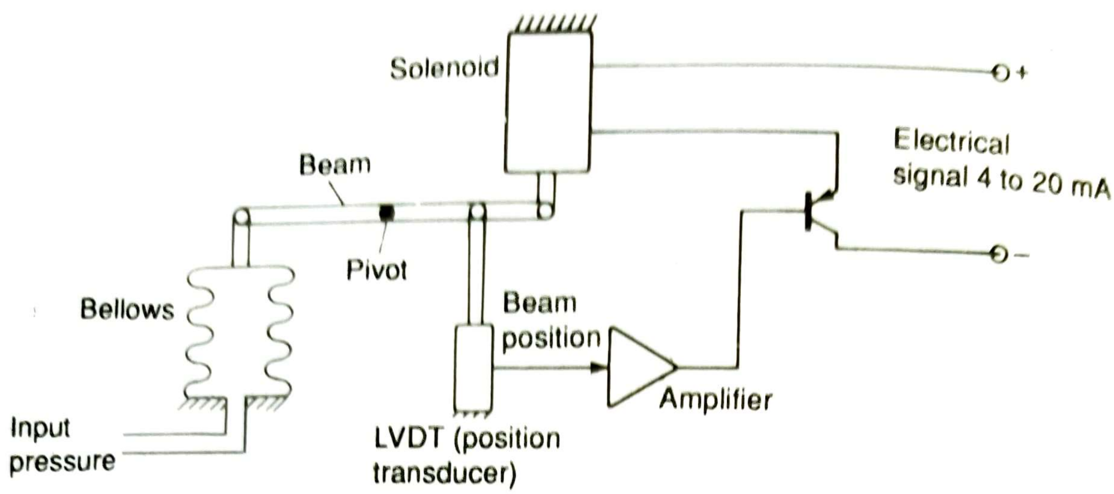


Figure 7.26 Pressure to current (P–I) converter

differential transformer). The electrical signal corresponding to the deflection is amplified and applied as current through a coil to produce a torque which brings the beam back to the null position. At balance, the coil force (proportional to output current) matches the force from the bellows (proportional to input signal pressure).

The zero offset (4 mA) in the electrical signal is sufficient to drive the amplifier in Figure 7.26, allowing the two signal wires to also act as the supply lines. This is known as two-wire operation. Most P–I converters operate over a wide voltage range (eg, 15 to 30 V). Often, the current signal of 4 to 20 mA is converted to a voltage signal (commonly in the range 1 to 5 V) with a simple series resistor.

Sequencing applications

Process control pneumatics is also concerned with sequencing ie, performing simple actions which follow each other in a simple order or with an order determined by sensors. Electrical equivalent circuits are formed with relays, solid state logic or programmable controllers.

A simple example of a pneumatic sequencing system is illustrated in Figure 7.27, where a piston oscillates continuously between two striker-operated limit switches LS_1 and LS_2. These shift the main valve V_1 with pilot pressure lines. The main valve spool has no spring return and remains in position until the opposite signal is applied. Shuttle valves V_2 and V_3 allow external signals to be applied via ports Y and Z.

Time is often ...

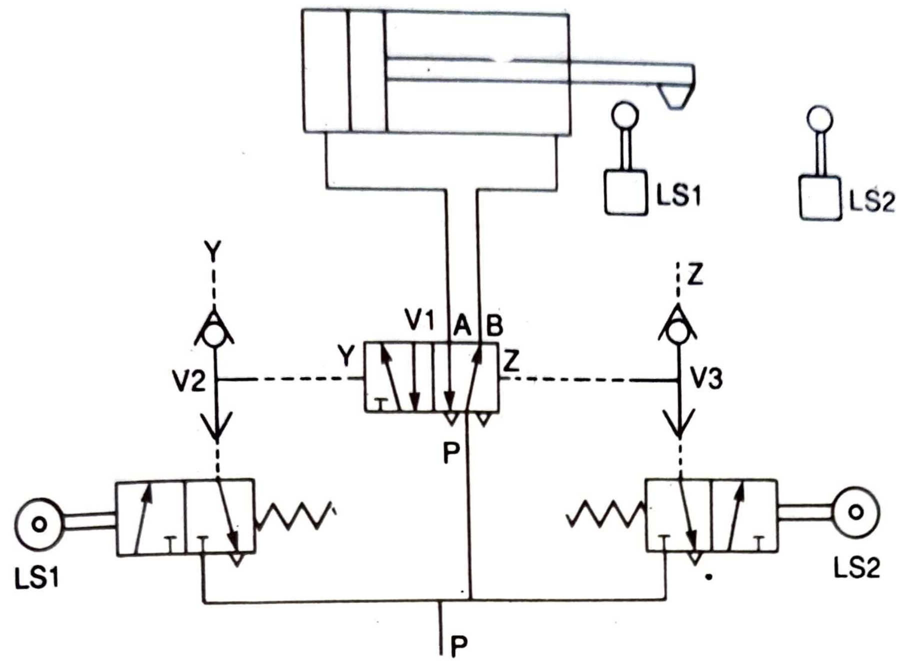
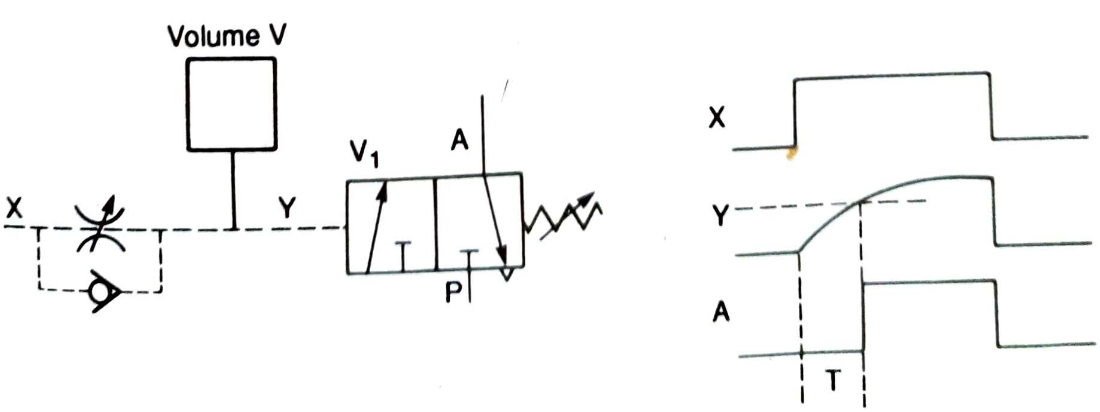


Figure 7.27 A sequencing example; the cylinder oscillates between LS1 and LS2

constructed as illustrated in Figure 7.28a. Input signal X is a pilot signal moving the spool in main valve V_1, but it is delayed by the restriction valve and the small reservoir volume V. When X is applied, pilot pressure Y rises exponentially giving a delay T before the pilot operating pressure is reached. When X is removed, the non-return valve quickly vents the reservoir giving a negligible off-delay. Figure 7.28b shows the response. As shown, the valve is a delay-on valve. If the non-return valve is reversed delay-off action is achieved.

Sequencing valves are used to tie pressure-controlled operations together. These act somewhat like a pilot-operated valve, but the



(b) Response

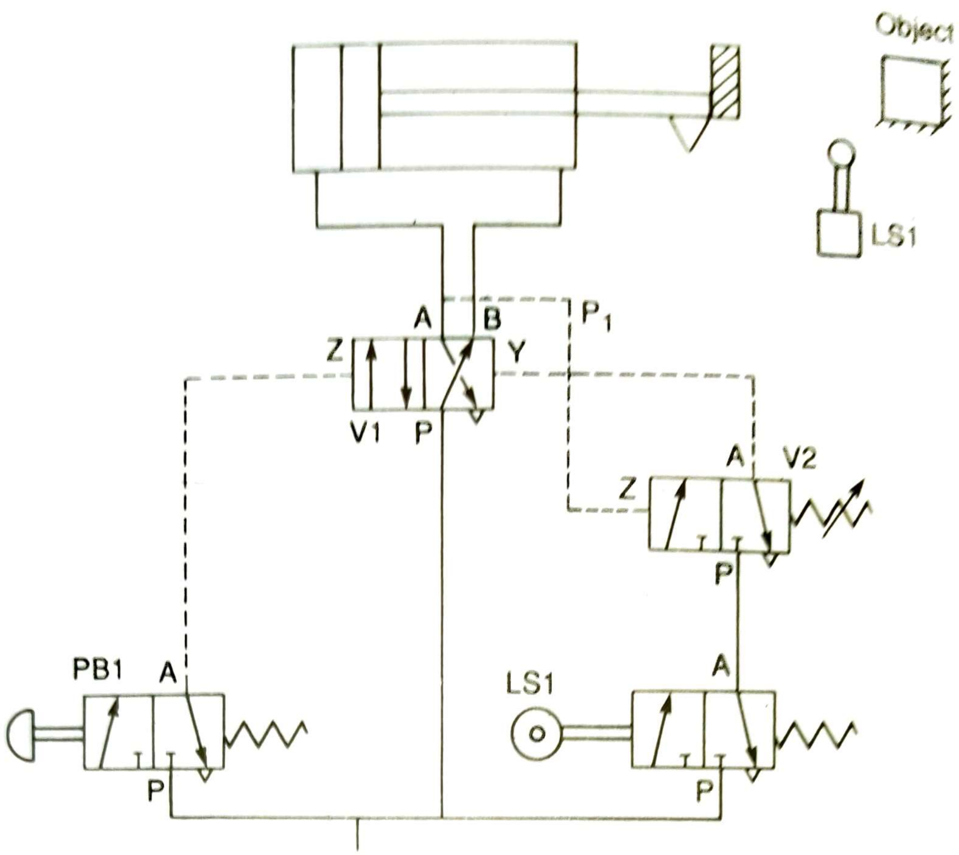


Figure 7.29 Sequencing valve application

designer can control the pressure at which the valve operates. A typical application is shown in Figure 7.29 where a cylinder is required to give a certain force to an object. Valve V_2 is the sequence valve and operates at a pressure set by the spring. The sequence is started by pushbutton PB_1, which shifts the pilot spool in the main valve V_1 causing the cylinder to extend. When the cylinder reaches full extension, limit switch LS_1 operates and pressure P_1 starts to rise. When the preset pressure is reached sequence valve V_2 operates, moving the spool in main valve V_1 and retracting the cylinder.

The two applications given so far have used limit switch operated valves to control sequences. Pneumatic promixity sensors can also be used. The reflex sensor of Figure 7.30 uses an annular nozzle jet of air the action of which removes air from the centre bore to give a light vacuum at the signal output X. If an object is placed in front of the sensor, flow is restricted and a significant pressure rise is seen at X. Another example is the interruptible jet sensor (Figure 7.31) which is simple in operation but uses more air. A typical application could be sensing the presence of a drill bit to indicate 'drill complete' in a pneumatically controlled machine tool. With no

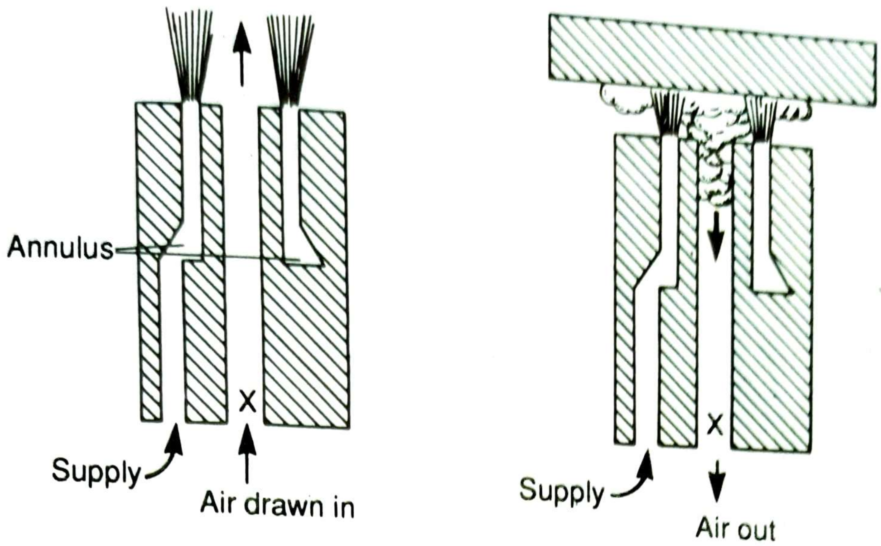


Figure 7.30 Reflex promixity switch

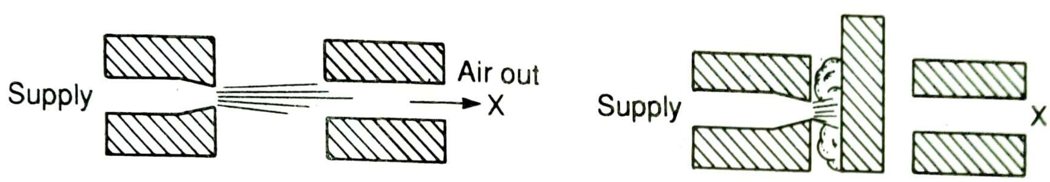


Figure 7.31 Interruptible jet limit switch

An object blocking this flow, causes X to fall to atmospheric pressure.

With both types of sensor, air consumption can be a problem. To reduce air usage, low pressure and low flow rates are used. Both of these results in a low pressure signal at X which requires pressure amplification or low pressure pilot valves before it can be used to control full pressure lines.

Logic devices (AND, OR gates and memories) are part of the electrical tool kit for sequencing applications. The pneumatic equivalent (Figure 7.32) uses the wall attachment or Coanda effect. A fluid stream exiting from a jet with a Reynolds number in excess of 1500 (giving very turbulent flow) tends to attach itself to a wall and remain there until disturbed (Figure 7.32a).

This principle is used to give a pneumatic set/reset (S-R) flip-flop memory in Figure 7.32b. If the set input is pulsed, the flow attaches itself to the right-hand wall, exiting via output Q. If the set input is then removed the Coanda effect keeps the flow on this route until the reset input is pulsed.

Figure 7.32c shows a fluidic OR/NOR gate. A small bias pressure keeps the jet along the right-hand wall, which causes it to exit via

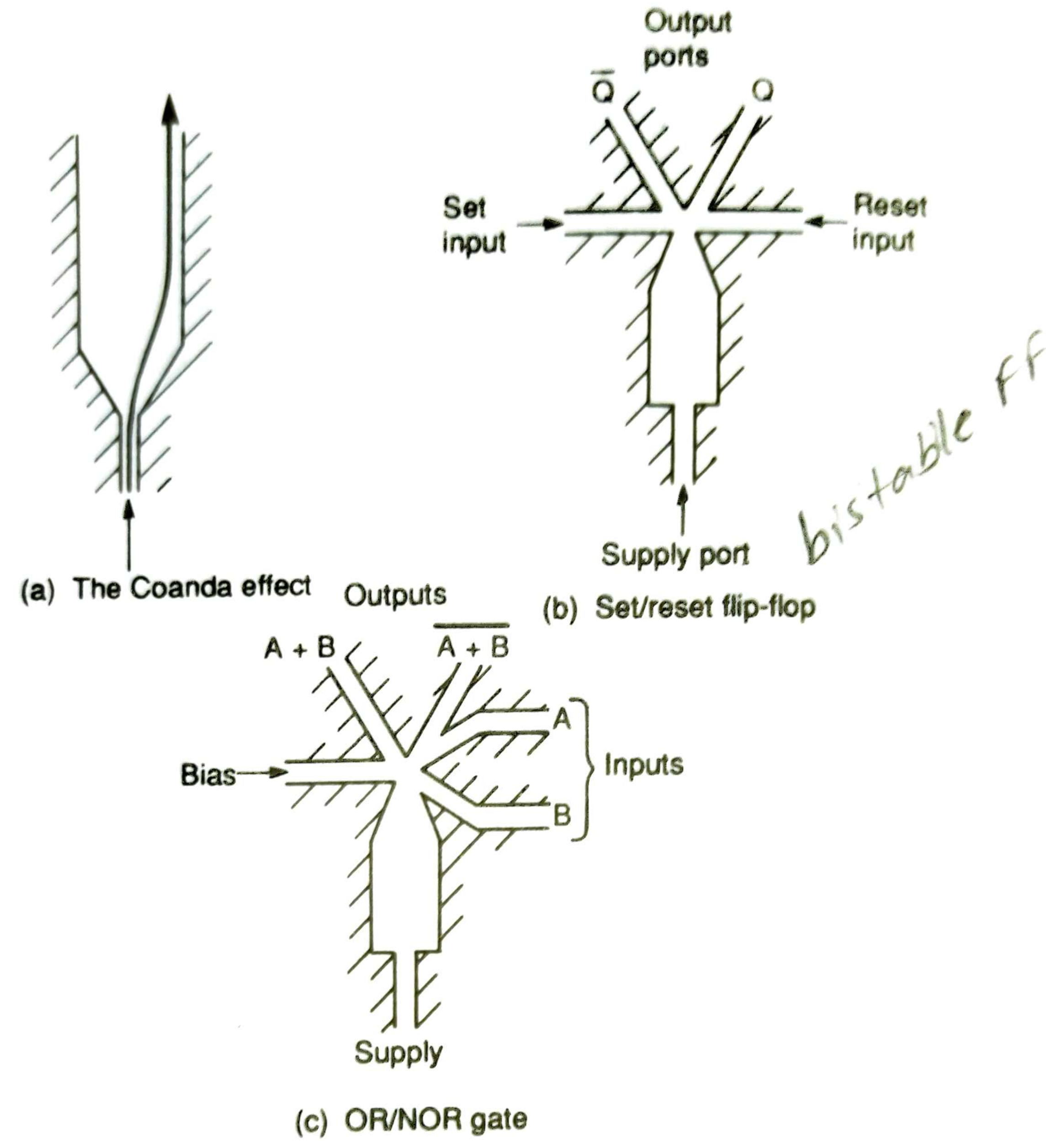


Figure 7.32 Fluidic logic

the right-hand port. If signal A or B is applied (at higher pressure than the bias) the flow switches over to the (A+B) output. When both A and B signals are removed, the bias pressure switches the flow back again.

Logic functions can also be performed by series connections of valves (to give the AND operation) shuttle valves (to give the OR operation) and pilot-operated spools (to give flip-flop memories). Valve V_1 in Figure 7.27, for example, acts as an S-R flip-flop memory.

Example 4-4 The motor in Example 4-1 is driven by a power amplifier with a gain of $K_a = 10$. The loop is closed, as is shown in Fig. 4-11. The tachometer gain is 17.25 V/1000 rpm.

(*a*) Calculate the time constant of the machine drive unit.

(*b*) Derive the steady-state equation of the machine drive unit.

(*c*) Calculate the input voltage V_c which causes the motor to rotate the 985 rpm at the no-load condition.

(*d*) Calculate the change in speed for a full-load (120 lb·in) condition.

SOLUTION

(*a*) The motor gain K_m is

$$K_m = \frac{1}{K_v} = \frac{60}{0.824 \times 2\pi} = 11.6 \text{ rpm/V}$$

From Eq. (4-29) the attenuation factor is

$$\alpha = \frac{1}{1 + (10 \times 11.6 \times 17.25/1000)} = \frac{1}{3}$$

The motor time constant is $\tau_m = 13$ ms; the drive system time constant is $\alpha\tau_m$, or 4.33 ms.

(*b*) At steady state the time constant τ_m does not affect the system performance, and consequently it can be eliminated from Eq. (4-28):

$$\omega = \alpha K_a K_m V_c - \frac{\alpha R K_m T_s}{K_t} \qquad (4\text{-}30)$$

The variables ω, V_c, and T_s in Eq. (4-30) can be either Laplace or time variables.

(*c*) At no-load, $T_s = 0$, and the voltage is

$$V_c = \frac{\omega}{\alpha K_a K_m} = 25.5 \text{ V}$$

(*d*) For a loaded motor the change in speed is

$$\frac{\alpha R K_m T_s}{K_t} = 26 \text{ rpm}$$

which is one-third of the speed change in the open-loop case (see Example 4-1).

4-3 COUNTING DEVICES

The transfer of information in digital form requires special circuits which are called digital circuits or logic circuits. The logic circuits are able to store data and instructions, receive new data, perform arithmetic operations, and transfer the results. They operate at two distinct voltage levels, corresponding to the 0 and 1 values of the boolean algebra variables. These levels are known as H (*h*igh), the more positive voltage, and L (*l*ow), the zero or less positive voltage.

The basic logic circuits may be divided into two groups:

1. Gates, in which the resulting output depends only on the present input
2. Storage elements, in which the resulting output depends on both the past and present input signals

The logic gates are devices which perform the arithmetic operations of boolean algebra. Every boolean operation has its corresponding gate: AND, OR, NAND, NOR, and EXCLUSIVE-OR. The gates are not discussed here, and it is assumed that the reader is familiar with their principles. Note that gates have a common characteristic: their output is a function of the present state of their inputs.

4-3.1 Flip-Flops

A different kind of logic circuit is an element capable of storing or memorizing information. In memory circuits, the output depends not only on the present level of inputs, but also on the past, or prior, sequence of inputs. The logic state of these circuits is changed by pulses, rather than by logic levels as in gates. A pulse is characterized by a temporary change in the logic level for a short period of time.

The basic memory circuit is the *flip-flop (FF)*, which is a binary storage device that has two distinct stable states, and it remains in one of them until it is directed to change it. The change between the two states is done by means of two inputs, termed *set* and *reset*. Whenever a bit of 1 logic level is stored, the device is said to be set. The operation which stores a 0 bit in a flip-flop is called the reset, or clear, operation, and the flip-flop is said to be in the reset state. For sensing the state, the flip-flop is provided with two outputs Q and Q'. When Q is at 1 logic level, Q' is at 0, and vice versa.

The most commonly used types of binary storage are the RS, JK, and T flip-flops. The T, or trigger, flip-flop (TFF), has only one input, denoted by T or CP (clock pulse). It changes its state each time that the input is triggered by a pulse or by the falling edge of the input signal. *Falling edge* means the transient change between 1 to 0 logic level.

Flip-flops are the basic elements of registers and counters which are used in NC systems. Registers consist of groups of identical flip-flops and are used to store binary information. For example, the binary number 1001 can be represented by a setup of 4 flip-flops, which is termed a 4-bit register. A 4-bit register can store a maximum of 16 different binary words.

4-3.2 Counters

The logic circuit of Fig. 4-12 consists of three TFFs, where the output of each one is connected to the CP input of the next stage. The falling edge at the output of each FF is used as the trigger pulse to the next one. Assume that the FFs have been reset, namely

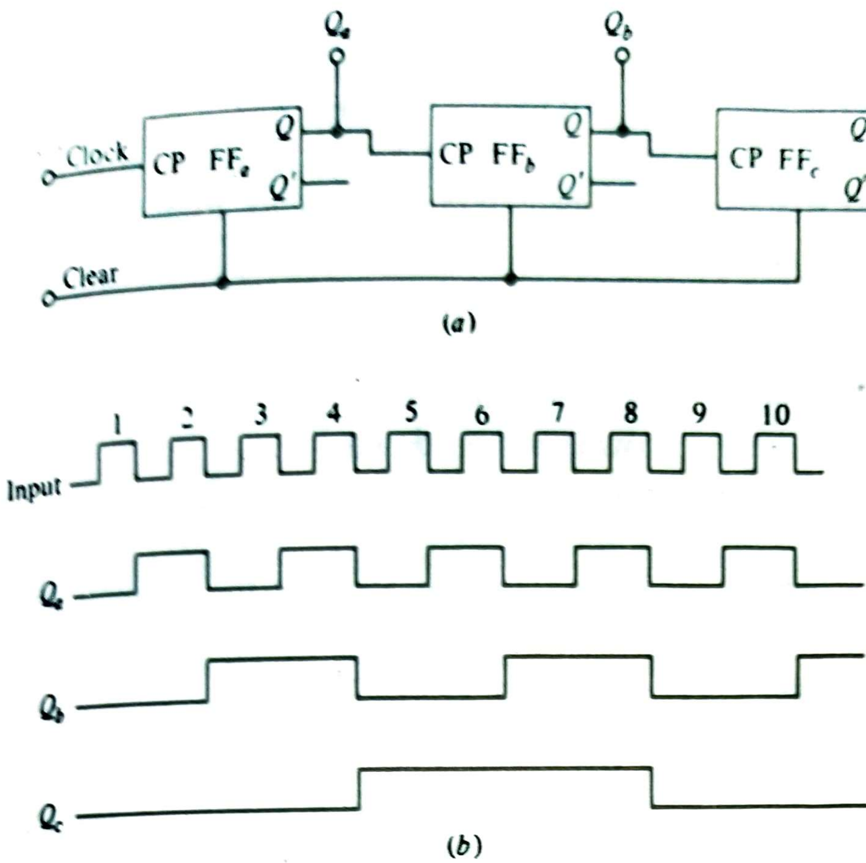


Figure 4-12 A 3-bit binary counter. (*a*) Logic diagram, (*b*) waveforms.

changes its state to $Q_a = 1$. The next pulse changes back the output to $Q_a = 0$, thus providing a falling edge to FF_b and changing its state to $Q_b = 1$. Similarly, FF_c will be triggered only when FF_b returns to the 0 state, and this will occur after four incoming pulses at the input terminal. The generated waveforms are shown in Fig. 4-12, and the FFs' operational states are summarized in Table 4-1.

Table 4-1 Binary counter states (Fig. 4-12)

Q_c	Q_b	Q_a	Pulse no.
0	0	0	Clear
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	4
1	0	1	5
1	1	0	6

MRT 281:INTRODUCTION TO SENSORS AND ACTUATORS

Coating Technologies

Magnetic Materials Market and Applications

PRESENTED BY
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Advantages of Coating

- This coating process, therefore, allows for reducing magnet manufacturing costs by eliminating expensive compounding and blending costs
- increasing production throughput
- reducing rejects
- and eliminating the need for secondary coatings in some applications.

Coating Technologies

- Corrosion continues to represent a challenging issue for magnet manufacturers because of the wide range of applications in severe environments .
- Coatings for sintered and bonded magnets include:
  - nickel plating
  - organic electrocoating
  - spray coatings
  - multiple layers of combination coatings for tough performance requirements.

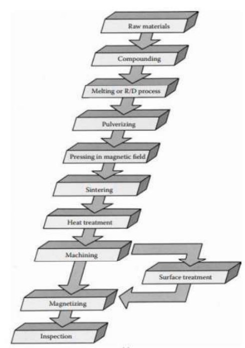

FIGURE 1.3
Rare-earth magnet manufacturing process: (a) sintered-based. (From Hitachi Metals Ltd., Hitachi Rare-Earth Magnets, 1999. With permission.)

- Some companies developed an improved coating process where magnetic particles are encapsulated with organic coatings.
- Some companies developed an even more advanced coating process with precise functional characteristics by applying thin multiple coatings over individual powder particles
  - Corrosion protection before, during, and after magnet manufacturing
  - Extremely uniform metal distribution with reduced geometric or dimensional scattering
  - Higher magnetic properties of the manufactured magnet
  - Minimized magnetic temperature degradation

Magnetic Materials Market and Applications

- Magnets serve as essential components in almost all domestic and industrial applications in the automotive, instrumentation, production machinery, aviation, marine, and space markets.
- Magnets are used in computers, electric motors, loudspeakers, smartcards, cell phones, tape recorders, cameras, camcorders, compact disk players, microwave ovens, kitchen robots, refrigerators, and washers and dryers, to name a few consumer products.
- Their contribution is often ignored because they are built into devices and are usually out of sight

- Magnets function as transducers and energy conversion devices, transforming energy from one form to another without any permanent loss of their energy.
- Energy conversion devices utilize PMs to convert mechanical-to-mechanical energy as attraction and repulsion motion
  - mechanical-to-electrical energy as generators and microphones
  - electrical-to mechanical energy as motors
  - Loudspeakers
  - mechanical energy to heat as eddy current

- **Cost, temperature, and manufacturing are the major barriers to the expanded use of neodymium magnets in automobiles**
- Cost barriers — neodymium not yet considered a ceramic replacement because of cost, system integration has potential in savings to offset system cost

• Thermal barriers — under-hood temperatures affected by engine compartment complexity, effect of operation and location of other heat-generating subsystems, component self-heating, and difficulties with predicting operating temperatures accurately

• Manufacturing barriers — feasibility of high volume production, fragile aspect of neodymium material, magnetizing and calibrating assembly, and difficulty of repair or rework

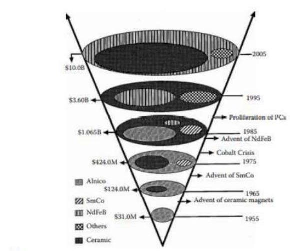

FIGURE 1.4
Growth of the PM market. (From Rashidi, S., NdFeB Opening Remarks, NdFeB '99 Conference, San Francisc April 12–14, 1999, p. 3. With permission.)

1)ferrite ceramic magnets
2)alnico alloys
3)rare-earth samarium-cobalt
4)neodymium magnets
5)others

- **Magnet manufacturers maintain that the following current trends in automotive system design should affect rare-earth magnet growth opportunities by increasing the penetration of electric motors in automobiles:**
- Electronic control of motors
- Power-generation technologies
- Motor technologies
- Minimizing parasitic engine losses
- Worldwide supply considerations

MRT 281:INTRODUCTION TO SENSORS AND ACTUATORS

STEPPER MOTOR

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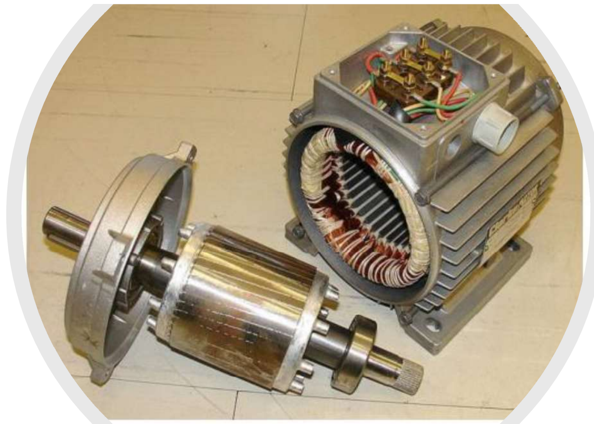


TYPE OF ELECTRICAL ACTUATORS

1.ELECTRICAL MOTOR

- DC SERVO MOTOR
- AC MOTOR
- STEPPER MOTOR

2.SOLENOIDS

Ac motor is divided into three types they are:

- Three phase motors
  - induction motor
  - synchronous motor
- Single phase motors
- Special motors

AC MOTOR

- A machine which converts electrical energy into mechanical energy is called as motor
- Motor is divided into two types depend upon the supply
  - AC MOTOR
  - DC MOTOR

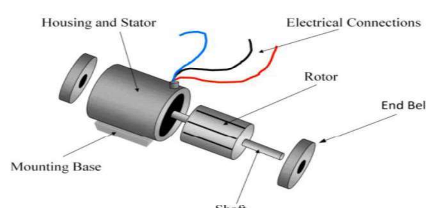
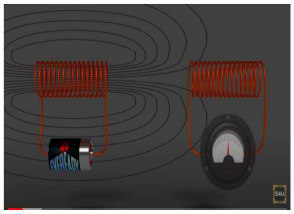


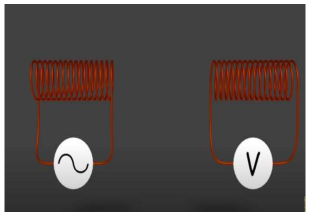
Fig.1: Motor Stator and Rotor

- A **rotor** is a rotating part of the AC motor
- The **stator** is the fixed or stationary part of the motor

Faraday's law of electromagnetic induction

- Faraday's law states that a current will be induced in a conductor which is exposed to a changing magnetic field





ROS

Faraday's law of electromagnetic induction

- The flux from the stator cuts the short-circuited coil in the rotor
- As the rotor coils are short-circuited, according to Faraday's law of electromagnetic induction, the current will start flowing through the coil of the rotor
- When the current through the rotor coils flows, another flux gets generated in the rotor.
- Now there are two fluxes, one is stator flux, and another is rotor flux.
- The rotor flux will be lagging in respect of the stator flux. Because of that, the rotor will feel a torque which will make the rotor to rotate

- A stepper motor is a special electrical machine which rotates in discrete angular steps in response to a programmed sequence of input electrical pulses.

Working Principle

- A magnetic interaction takes place between the rotor and the stator, which make rotor move.

Construction

- The stator has windings
- The rotor is of salient structure without any windings

STEPPER MOTOR

Used in Dot Matrix Printer **Used in CD-ROM Drive**

Types of Stepper Motor

1. **Variable Reluctance SM**

Reluctance:the resistance to magnetic flux ,offered by a magnetic circuit

2. **Permanent Magnet SM**
3. **Hybrid SM**

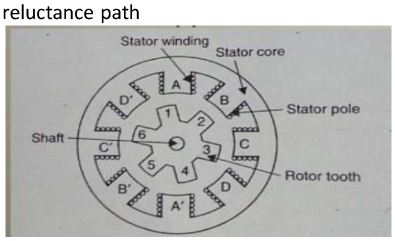
Application

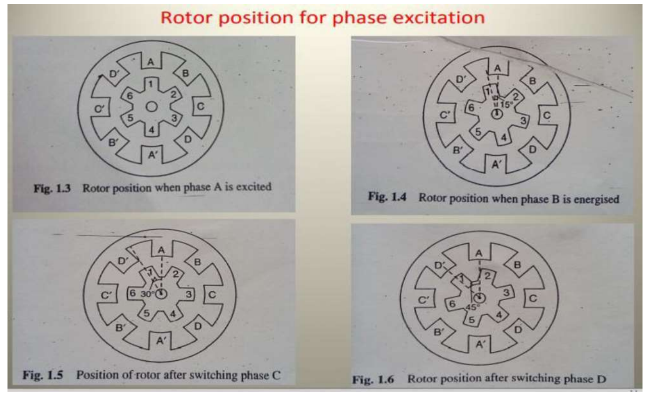
Application of stepper motor in diverse areas ranging from a small wrist watch to artificial satellites.

- Power range 1W to 2.5KW
- Torque range 1μN to 40 Nm

Variable reluctance motor

- Variable reluctance stepper motor works on the principle that a magnetic material placed in magnetic field experience a force to align minimum reluctance path





Rotor teeth can be assume any position until the stator winding energised.For a four phase ,eight pole single stack VR steeper motor operation truth table given below and the angle rotate by rotor is given by

Φ=360/MxNr degree

Where

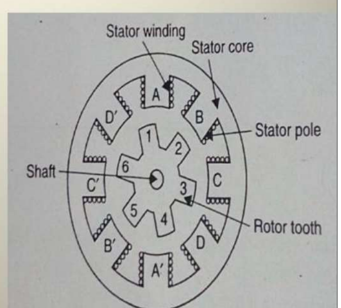
M = the number of stator phase

N= the number of rotor phase

In the present case M=4,Nr=6

Φ=360/4x6 degree

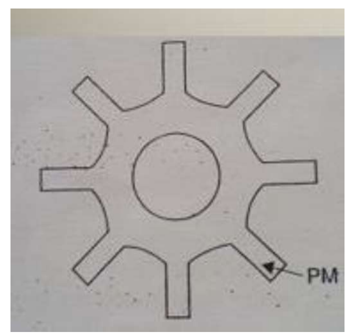
Φ=15 degree



1.1 Four-phase, eight-pole single-stack VR stepper m

Permanent Magnet Stepper motor

- Permanent magnet (PM) stepper motor is another version of stepper motor
- Its construction is similar to that of a VR stepper motor.
- Stator consist of a salient poles wound with concentric coils.
- The rotor carries no winding but has permanent magnets.



Switching sequence

Phase	S-1	S-2	S-3	S-4	Angle (Deg)
A	1	0	0	0	0
B	0	1	0	0	15
C	0	0	1	0	30
D	0	0	0	1	45
A	1	0	0	0	60

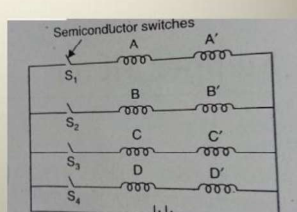
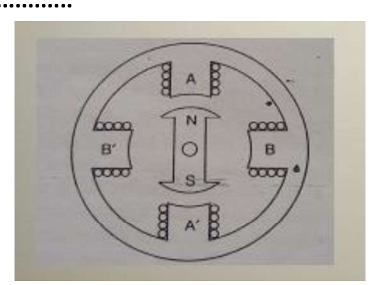


Fig. 1.2 Switching circuit

- Due to the difficulty in manufacturing small PMs, the number of poles in the rotor is limited and the step size is relatively large in the range 300 to 900

Working...................



- To study the principle of operation of PM stepper motor, a two phase motor is considered.
- It has four stator poles and two rotor poles.
- The stator has winding on its poles.

•When a phase is energized, it sets up a magnetic flux and rotor will position to lock its N pole and S pole to stator S pole and N pole respectively.

- •Coils wound on poles A and A’ are connected in series to form phase A same as for phase B.
- •The step angle is 360/(2x2x15)=60
- •The tooth pitch is 360/15=240

Hybrid stepper motor

• Its operation based on the combined principle of both PM and VR stepper motor.

•HSM is the best choice for the application where small step angles and high starting torque are essential.

Working......

Consider a four pole, two phase HSM with 15 rotor teeth on each rotor section,as shown in figure.

References......

- https://www.linearmotiontips.com/how-does-the-number-of-stator-phases-affect-stepper-motor-performance/

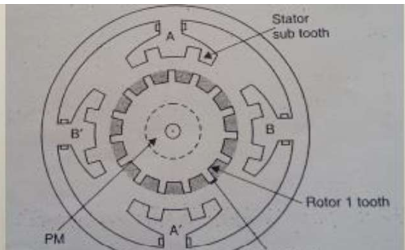


Fig. 1.23 Two-phase, four-pole HSM

Hybrid stepper motor

CONTENT BEYOND SYLLABUS

1. AUTOMOTIVE COMPONENTS

Automotive electronics are electronic systems used in road vehicles, such as: engine management, ignition, radio, carputers, telematics, in-car entertainment systems and others. Electronic systems have become an increasingly large component of the cost of an automobile, from only around 1% of its value in 1950 to around 30% in 2010.

The earliest electronics systems available as factory installations were vacuum tube car radios, starting in the early 1930s. The development of semiconductors after WWII greatly expanded the use of electronics in automobiles, with solid-state diodes making the automotive alternator the standard after about 1960, and the first transistorized ignition systems appearing about 1955.

The availability of microprocessors after about 1974 made another range of automotive applications economically feasible. In 1978 the Cadillac Seville introduced a "trip computer" based on a 6802 microprocessor. Electronically-controlled ignition and fuel injection systems allowed automotive designers to achieve vehicles meeting requirements for fuel economy and lower emissions, while still maintaining high levels of performance and convenience for drivers. Today's automobiles contain a dozen or more processors, in functions such as engine management, transmission control, climate control, antilock braking, passive safety systems, navigation, and other functions.

Modern electric cars rely on power electronics for the main propulsion motor control, as well as managing the battery system. Future autonomous cars will rely on powerful computer systems, an array of sensors, networking, and satellite navigation, all of which will require electronics.

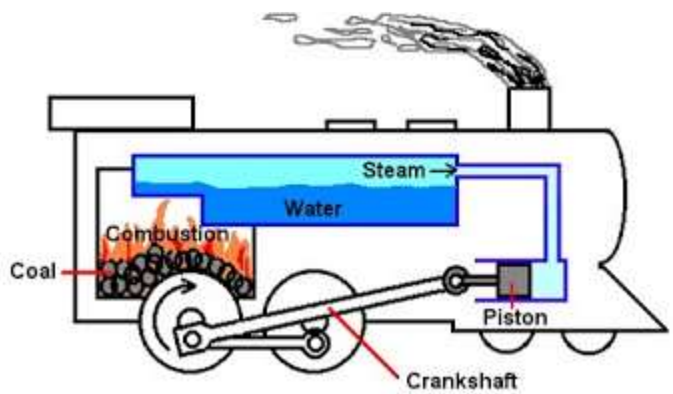
WHAT IS ENGINE? WHAT ARE MAIN TYPES OF ENGINE?

Today we will discuss about engine and types of engine used in automobile. Any device which can convert heat energy of fuel into mechanical energy is known as engine or heat engine. Engine is widely used in automobile industries or we can say that engine is the heart of an automobile. Basically engine may be classified into two types.

Types of Engine:

EXTERNAL COMBUSTION (E.C.) ENGINE

An engine in which combustion of fuel take place outside of the cylinder is known as EC engine. In this type of engine heat, which is generated by burning of fuel is used to convert the water or other low boiling temperature fluid into steam. This high pressure steam used to rotate a turbine. In this engine we can use all solid, liquid and gases fuel. These engines are generally used in driving locomotive, ships, generation of electric power etc.



Advantages of E.C. engine-

- In these engines starting torque is generally high.
- Because of external combustion we can use cheaper fuels as well as solid fuel.

- They are more flexible compare to internal combustion engines.

INTERNAL COMBUSTION (I.C.) ENGINE

It is an engine in which combustion of fuel take place inside the engine. When the fuel burns inside the engine cylinder, it generates a high temperature and pressure. This high pressure force is exerted on the piston (A device which free to moves inside the cylinder and transmit the pressure force to crank by use of connecting rod), which used to rotate the wheels of vehicle. In these engines we can use only gases and high volatile fuel like petrol, diesel. These engines are generally used in automobile industries, generation of electric power etc.

Advantages of I.C. engine-

- It has overall high efficiency over E.C. engine.
- These engines are compact and required less space.
- Initial cost of I.C. engine is lower than E.C. engine.
- This engine easily starts in cold because of it uses high volatile fuel.

TYPES OF I.C. ENGINE

I.C. engine is widely used in automobile industries so it is also known as automobile engine. An automobile engine may be classified in many manners. Today I am going to tell you some important classification of an automobile engine.

According to number of stroke:

1. <u>Two stroke engine</u>

In a two stroke engine a piston moves one time up and down inside the cylinder and complete one crankshaft revolution during single time of fuel injection. This type of engine has high torque compare to four stroke engine. These are generally used in scooters, pumping sets etc.

2. <u>Four stroke engine</u>

In a four stroke engine piston moves two times up and down inside the cylinder and complete two crankshaft revolutions during single time of fuel burn. This type of engines has high average compare to two stroke engine. These are generally used in bikes, cars, truck etc.

According to design of engine:

1. Reciprocating engine (piston engine)

In reciprocating engine the pressure force generate by combustion of fuel exerted on a piston (A device which free to move in reciprocation inside the cylinder). The piston starts reciprocating motion (too and fro motion). This reciprocating motion converts into rotary motion by use of crank shaft. So the crank shaft starts to rotate and make rotate the wheels of the vehicle. These are generally used in all automobile.

2. Rotary engine (Wankel engine)

In rotary engine there is a rotor which frees to rotate. The pressure force generated by burning of fuel is exerted on this rotor so the rotor rotate and starts to rotate the wheels of vehicle. This engine is developed by Wankel in 1957. This engine is not used in automobile in present days.

According to fuel used:

1. Diesel engine

These engines use diesel as the fuel. These are used in trucks, buses, cars etc.

2. Petrol engine

These engines use petrol as the fuel. These are used in bikes, sport cars, luxury cars etc.

3. Gas engine

These engines use CNG and LPG as the fuel. These are used in some light motor vehicles.

4. Electric engine

It is eco-friendly engine. It doesn’t use any fuel to burn. It uses electric energy to rotate wheel.

According to method of ignition:

1. Compression ignition engine

In these types of engines, there is no extra equipment to ignite the fuel. In these engines burning of fuel starts due to temperature rise during compression of air. So it is known as compression ignition engine.

2. Spark ignition engine

In these types of engines, ignition of fuel start by a spark, generated inside the cylinder by some extra equipment (Spark Plug). So it is known as spark ignition engine.

According to number of cylinder:

1. Single cylinder engine

In this type of engines have only one cylinder and one piston connected to the crank shaft.

Single Cylinder Engine

2. Multi-cylinder engine

In this type of engines have more than one cylinder and piston connected to the crank shaft.

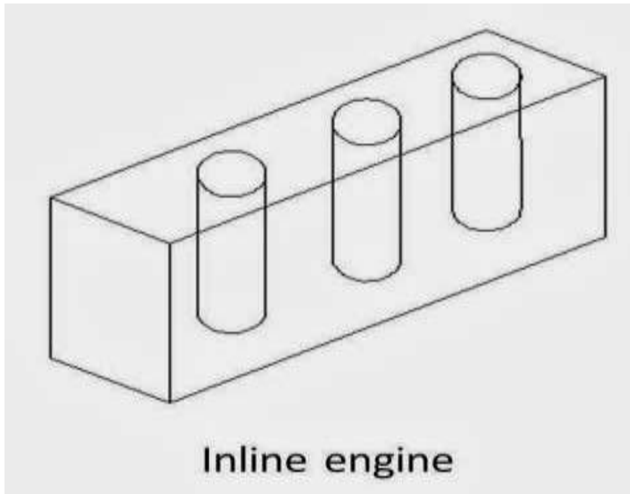
Double Cylinder Engine

Multi Cylinder Engine

According to arrangement of cylinder:

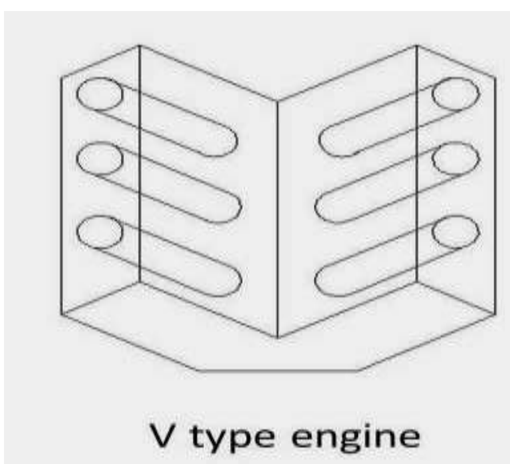
1. In-line engine

In this type of engines, cylinders are positioned in a straight line one behind the other along the length of the crankshaft.



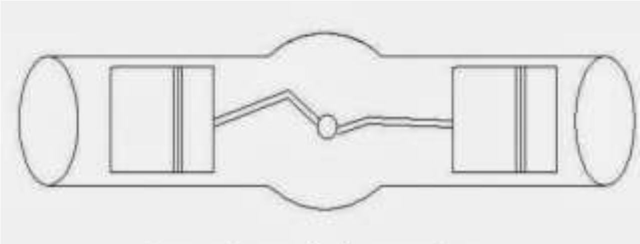
2. V-type engine

An engine with two cylinder banks inclined at an angle to each other and with one crankshaft known as V-type engine.



3. Opposed cylinder engine

An engine with two cylinders banks opposite to each other on a single crankshaft (V-type engine with 180o angle between banks).



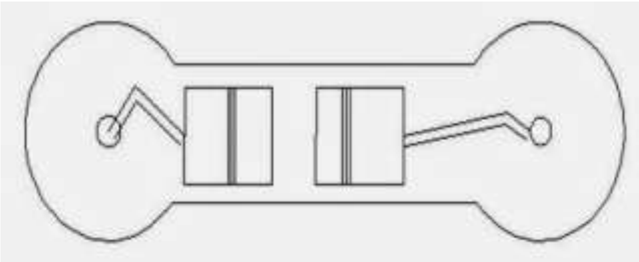
Opposite cylinder engine

4. W-type engine

An engine same as V-type engine except with three banks of cylinders on the same crankshaft known as W-type engine.

5. Opposite piston engine

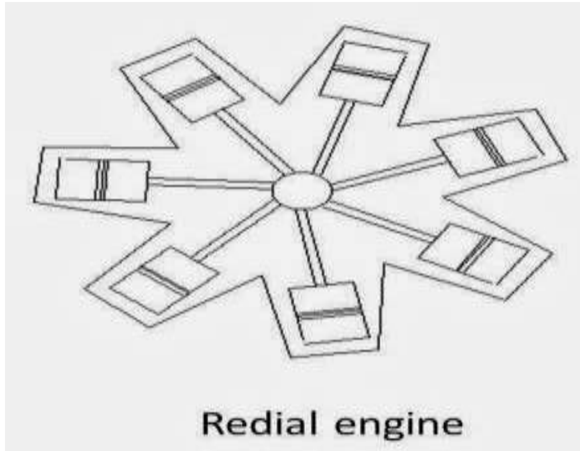
In this type of engine there are two pistons in each cylinder with the combustion chamber in the center between the pistons. In this engine, a single combustion process causes two power strokes, at the same time.



Opposite piston engine

6. Radial engine

It is an engine with pistons positioned in circular plane around the central crankshaft. The connecting rods of pistons are connected to a master rod which, in turn, connected to the crankshaft.



According to air intake process:

1. Naturally aspirated

In this types of engine intake of air into cylinder occur by the atmospheric pressure.

2. Supercharged engine

In this type of engine air intake pressure is increased by the compressor driven by the engine crankshaft.

3. Turbocharged engine

In this type of engine intake air pressure is increase by use of a turbine compressor driven by the exhaust gases of burning fuel.

COMPONENTS OF IC ENGINES

The burning heart of our fast cars, yeah you are right, I am talking about engine. It's the power unit we have to spin our car wheels. The entire thrill we have got while driving depends on the capacity of this power unit, and the limits up-to which we can push its components to operate safely. It is the combination of all parts of an engine that makes a car to move faster and faster.

So let's just dig out what it's components are, and how precisely they must be engineered to get the maximum power out of an engine.

Main Parts of an Engine are;

1) Camshaft:

Camshaft is a type of rotating device or apparatus used in piston engines for propelling or operating poppet valves. Camshaft comprises of series of cams that regulates the opening and closing of valves in the piston engines. The camshaft works with the help of a belt, chain and gears.

2) Crankshaft:

Crankshaft is a device, which converts the up and down movement of the piston into rotatory motion. This shaft is presented at the bottom of an engine and its main function is to rotate the pistons in a circular motion. Crankshaft is further connected to flywheel, clutch, main shaft of the transmission, torque converter and belt pulley.

To convert Reciprocating motion of the Piston into Rotary motion, the Crankshaft and Connecting Rod combination is used. The Crankshaft which is made by Steel Forging or

Casting is held on the Axis around which it rotates, by the Main Bearings, which is fit round the main Journals provided.

There are always at least two such bearings, one at the rare end and other at front end. the increase in number of Main Bearings for a given size of the Crankshaft means less possibility of Vibration and Distortion.

But it will also increase the difficulty of correct alignment in addition to increased production cost. The Main Bearings are mounted on the Crankcase of the Engine. The Balance weight or Counter weight keep the system in perfect balance.

The Crank Webs are extended and enlarged on the side of Journal opposite the Crank Throw so as to from balance weights. The Crankshaft may be made from Carbon Steel, Nickel Chrome or other Alloy Steel.

3) Connecting Rod:

Connecting rods are made of metals, which are used, for joining a rotating wheel to a reciprocating shaft. More precisely, connecting rods also referred to as con rod are used for conjoining the piston to the crankshaft.

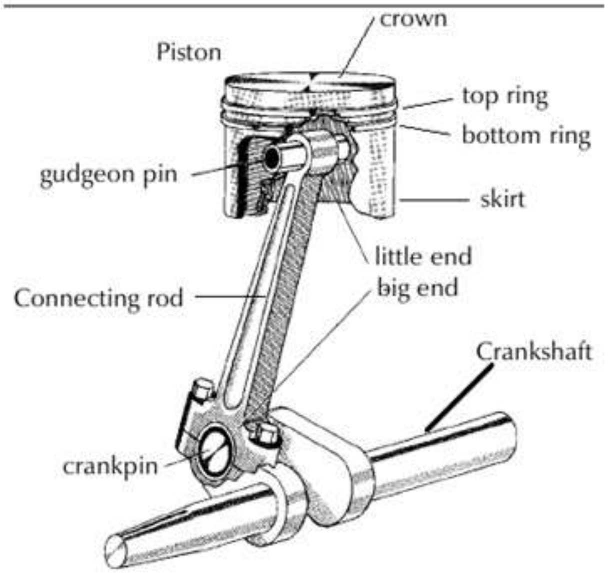
The load on the piston due to combustion of fuel in the combustion chamber is transmitted to crankshaft through the connecting rod. One end of connecting rod known as small end and is connected to the piston through gudgeon pin while the other end known as big end and is connected to crankshaft through crank pin.

Connecting rods are usually made up of drop forged I section. In large size internal combustion engine, the connecting rods of rectangular section have been employed. In such cases, the larger dimensions are kept in the plane of rotation.

In petrol engine, the connecting rod's big end is generally split to enable its clamping around the crankshaft. Suitable diameter holes are provided to accommodate connecting rod bolts for clamping. The big end of connecting rod is clamped with crankshaft with the help of connecting rod bolt, nut and split pin or cotter pin.

Generally, plain carbon steel is used as material to manufacture connecting rod but where low weight is most important factor, aluminum alloys are most suitable. Nickel alloy steel are also used for heavy duty engine's connecting rod.

Connecting rods can be made of steel, aluminum, titanium, iron and other types of metals.

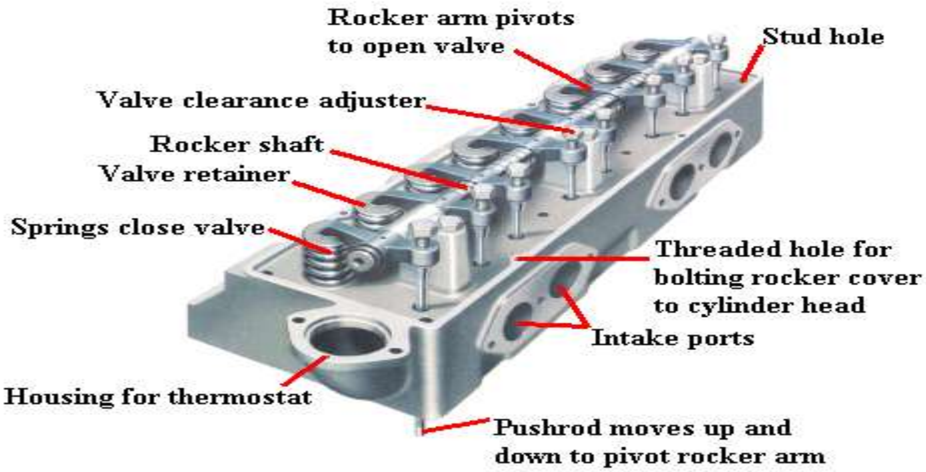


4) Crank Case:

A crankcase is a metallic cover that holds together the crankshaft and its attachments. It is the largest cavity within an engine that protects the crankshaft, connecting rods and other components from foreign objects. Automotive crankcases are filled with air and oil, while Magnesium, Cast Iron, Aluminum and alloys are some common materials used to make crankcases.

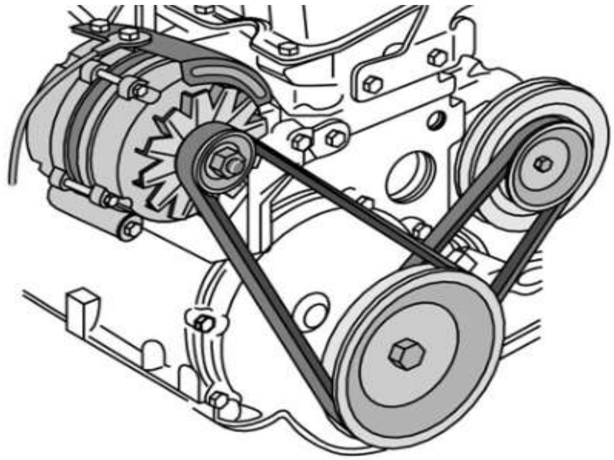
5) Cylinder Heads:

Cylinder heads refers to a detachable plate, which is used for covering the closed end of a cylinder assembled in an automotive engine. It comprises of combustion chamber valve train and spark plugs. Different types of automobiles have different engine configurations such as Straight engine has only one cylinder head while a engine has two cylinder heads.



6) Engine Belts:

Engine belts are the bands made of flexible material used for connecting or joining two rotating shafts or pulleys together. These belts work in coordination with wheels and axles for transferring energy. When the wheels or shafts are positioned at extremely different angles, then the engine belts have the ability to change the direction of a force. Engine pulley is a type of machine or a wheel having either a broad rim or groomed rim attached to a rope or chain for lifting heavy objects.



7) Engine Oil System:

Oil is one of the necessities of an automobile engine. Oil is distributed under strong pressure to all other moving parts of an engine with the help of an oil pump. This oil pump is placed at the bottom of an engine in the oil pan and is joined by a gear to either the crankshaft or the camshaft. Near the oil pump, there is an oil pressure sensor, which sends information about the status of oil to a warning light or meter gauge.

The different parts of engine oil systems include:

a) Engine Oil
b) Engine Oil Cooler
c) Engine Oil Filter
d) Engine Oil Gaskets
e) Engine Oil Pan
f) Engine Oil Pipe

8) Engine Valve:

Automobile engine valves are devices that regulate the flow of air and fuel mixture into the cylinder and assist in expelling exhaust gases after fuel combustion. They are indispensable to the system of coordinated opening and closing of valves, known as valve train. Engine valves are made from varied materials such as Structural Ceramics, Steels, Superalloys and Titanium alloys. Valve materials are selected based on the temperatures and pressures the valves are to endure.

The primary components of engine valve are:

a) Inlet Valve

b) Exhaust Valve

c) Combination Valve

d) Check Valve

e) EGR Valve

f) Thermostat Valve

g) Overhead Valve

h) Valve Guide

i) Schrader Valve

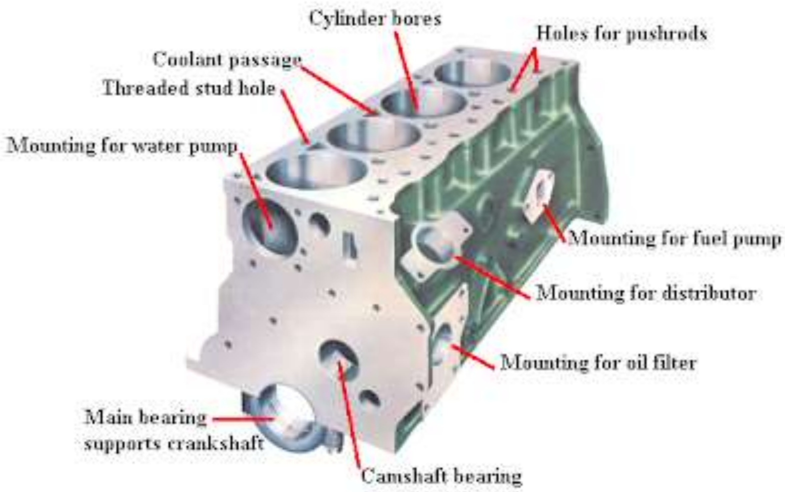
j) Vaccum Delay Parts

Inlet Valve & Exhaust Valve-

Function-Inlet valve allow the fresh charge of air-fuel mixture to enter the cylinder bore.Exhaust valve permits the burnt gases to escape from the cylinder bore at proper timing.

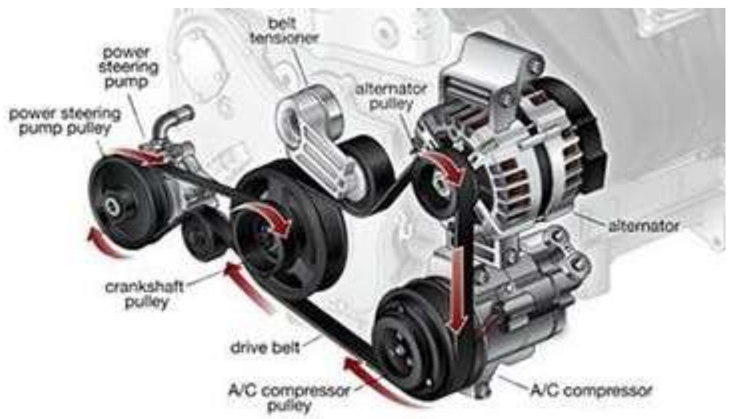
9) Engine Block:

An engine block is a metal casting that serves as a basic structure on which other engine parts are installed. A typical block contains bores for pistons, pumps or other devices to be attached to it. Even engines are sometimes classified as small-block or big-block based on the distance between cylinder bores of engine blocks. Engine blocks are made from different materials including Aluminum alloys, gray cast iron, ferrous alloys, white iron, gray iron, ductile iron, malleable iron, etc.



10) Engine Pulley:

An engine pulley is a wheel with a groove around its circumference, upon which engine belts run and transmit mechanical power, torque and speed across different shafts of an engine. An engine houses pulley units of different sizes for cam shaft drive, accessory drive and timing belts. Molded plastics, iron and steel are normally used to make engine pulleys.



11) Engine Brackets:

An engine bracket is a metallic part used to join an engine mount to the power unit or the body of a vehicle. These auto parts are installed between a vehicle's body and power unit to dampen the vibrations generated by the engine, thus preventing a vehicle's body from shaking due to the vibrations. Engine brackets are made from Ductile Iron Cast, Aluminum, Polypropylene, Fiberglass and alloys.

12) Engine Mounting Bolts:

Automotive mounting bolts secure different automobile components viz. air bags, brake fittings, etc. on to a supporting structure. Likewise, engine mounting bolts help secure an automobile's engine in place. Based on usage, a number of materials such as alloys, silicon bronze, bronze, ceramic, carbon, aluminum, nylon, phosphor bronze, nickel silver, plastic, titanium, zirconium and stainless steel are utilized to produce these bolts.

13) Piston:

Piston is a cylindrical plug which is used for moving up and down the cylinder according to the position of the crankshaft in its rotation. Piston has multiple uses and functions. In the case of four-stroke engine the piston is pulled or pushed with the help of crankshaft while in the case of compression stroke, piston is pushed with the powerful explosion of mixture of air and fuel.

Piston comprises of several components namely:

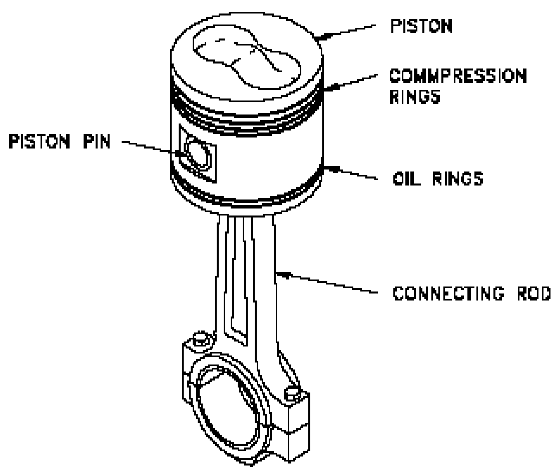
a) Piston Pins
b) Piston Floor Mat
c) Piston Rings
d) Piston Valve

14) Piston rings:

Piston rings provide a sliding seal between the outer edge of the piston and the inner edge of the cylinder. The rings serve two purposes:

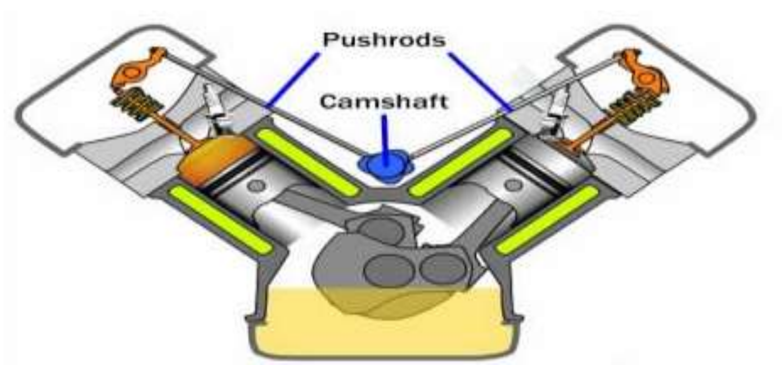
· They prevent the fuel/air mixture and exhaust in the combustion chamber from leaking into the sump during compression and combustion.

· They keep oil in the sump from leaking into the combustion area, where it would be burned and lost.



15) Push Rods:

Push rods are thin metallic tubes with rounded ends that move through the holes within a cylinder block and head, to actuate the rocker arms. Pushrods are found in valve-in-head type engines and are essential for the motion of engine valves. Some commonly used materials for manufacturing pushrods are Titanium, Aluminum, Chrome Moly and Tempered Chrome Moly.



16) Valve train:

Valve train consists of various components and parts, which enables valves to operate and function smoothly. Valve train comprises of three main components: camshafts, several components which are used for turning the camshaft's rotating movement into reciprocating movement, and lastly valves and its various parts.

The primary components of valve train are:

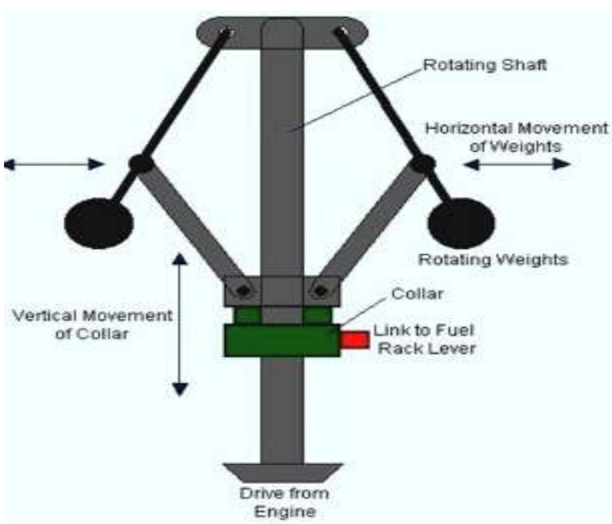
a) Tappet

b) Rocker Arms

c) Valve Timing System

17) Governor

It controls the speed of engine at a different load by regulating fuel supply in diesel engine. In petrol engine, supplying the mixture of air-petrol and controlling the speed at various load condition.



18) Carburettor

It converts petrol in fine spray and mixes with air in proper ratio as per requirement of the engine.

19) Fuel Pump

This device supplies the petrol to the carburettor sucking from the fuel tank.

20) Spark Plug

This device is used in petrol engine only and ignite the charge of fuel for combustion.

21) Fuel Injector

This device is used in diesel engine only and delivers fuel in fine spray under pressure.

22) Gudgeon Pin

Connects the piston with small end of connecting rod.

This pin connects the piston with small end of the connecting rod, and also known as piston pin. It is made up of case hardened steel and accurately ground to the required diameters. Gudgeon pins are made hollow to reduce its weight, B resulting low inertia effect of reciprocating parts.

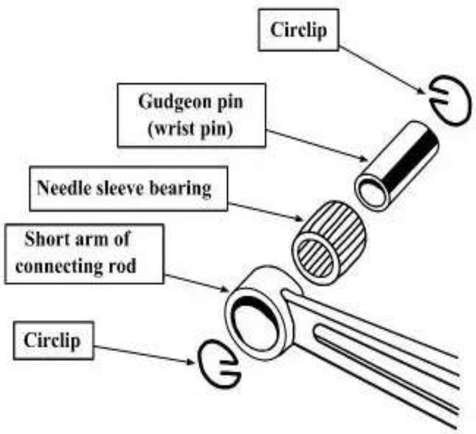
This pin is also known as "Fully Floating" as this is free to turn or oscillate both in the piston bosses as well as the small end of the connecting rod. There are very less chances of seizure in this case but the end movement of the pin must be restricted to score the cylinder walls. This can be achieved by using any one of the following three methods,

A) One spring circlip at each end is fitted into the groove in the piston bosses.

B) On spring circlip is provided in the middle.

C) Bronze or Aluminium pads are fitted at both ends of the pin, which prevents the cylinder walls from being damaged.

The gudgeon pin may also be semi-floating type, in which either the pin is free to turn or oscillate in the small end bearing but secured in the piston bosses or it may secured in the small end bearing and allowed a free oscillating movement in the piston bosses. This method provides more bearing area at the bosses and hence no need for providing bushes there in, is preferred.

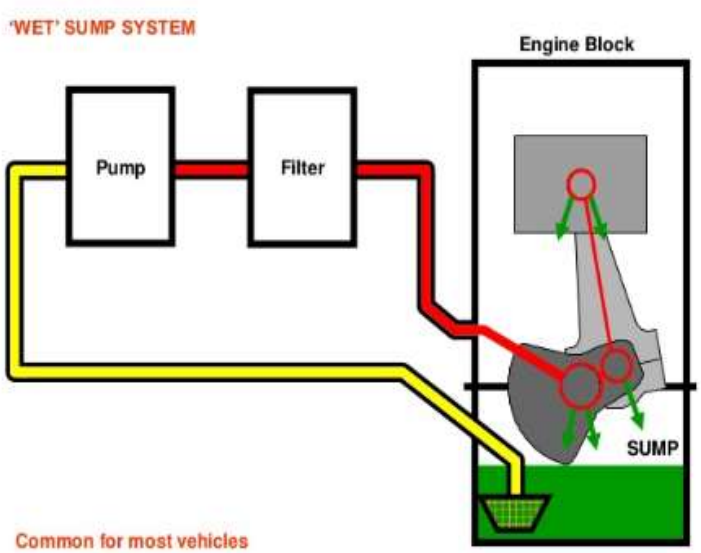


23) Crank Pin

Hand over the power and motion to the crank shaft which come from piston through connecting rod.

24) Sump

The sump surrounds the crankshaft. It contains some amount of oil, which collects in the bottom of the sump (the oil pan).



25) Distributor –

It operates the ignition coil making it spark at exactly the right moment. It also distributes the spark to the right cylinder and at the right time. If the timing is off by a fraction then the engine won't run properly.

26) Gasket

A wide variety of materials are used in making gaskets like Teflon, glass-fiber, silicon etc. It is generally a paper like sheet which is placed between engine block and engine head. As we have already discussed that we have both water and oil vents in engine block, so gasket gives insulation from water or oil leaking into engine cylinder or air-fuel mixture from engine cylinder leaking out from joint of engine block and engine head. Aluminum engine blocks are preferred over cast iron because it expends more on heating thus compressing the gasket more, increases the workability of gasket, thus reducing the chances of leakage.

2. ADAPTIVE CRUISE CONTROL

Two companies are developing a more advanced cruise control that can automatically adjust a car's speed to maintain a safe following distance. This new technology, called **adaptive cruise control**, uses forward-looking radar, installed behind the grill of a vehicle, to detect the speed and distance of the vehicle ahead of it.

Adaptive cruise control is similar to conventional cruise control in that it maintains the vehicle's pre-set speed. However, unlike conventional cruise control, this new system can automatically adjust speed in order to maintain a proper distance between vehicles in the same lane. This is achieved through a **radar headway sensor**, **digital signal processor** and **longitudinal controller**. If the lead vehicle slows down, or if another object is detected, the system sends a signal to the engine or braking system to decelerate. Then, when the road is clear, the system will re-accelerate the vehicle back to the set speed.

What is adaptive cruise control, and how does it work?

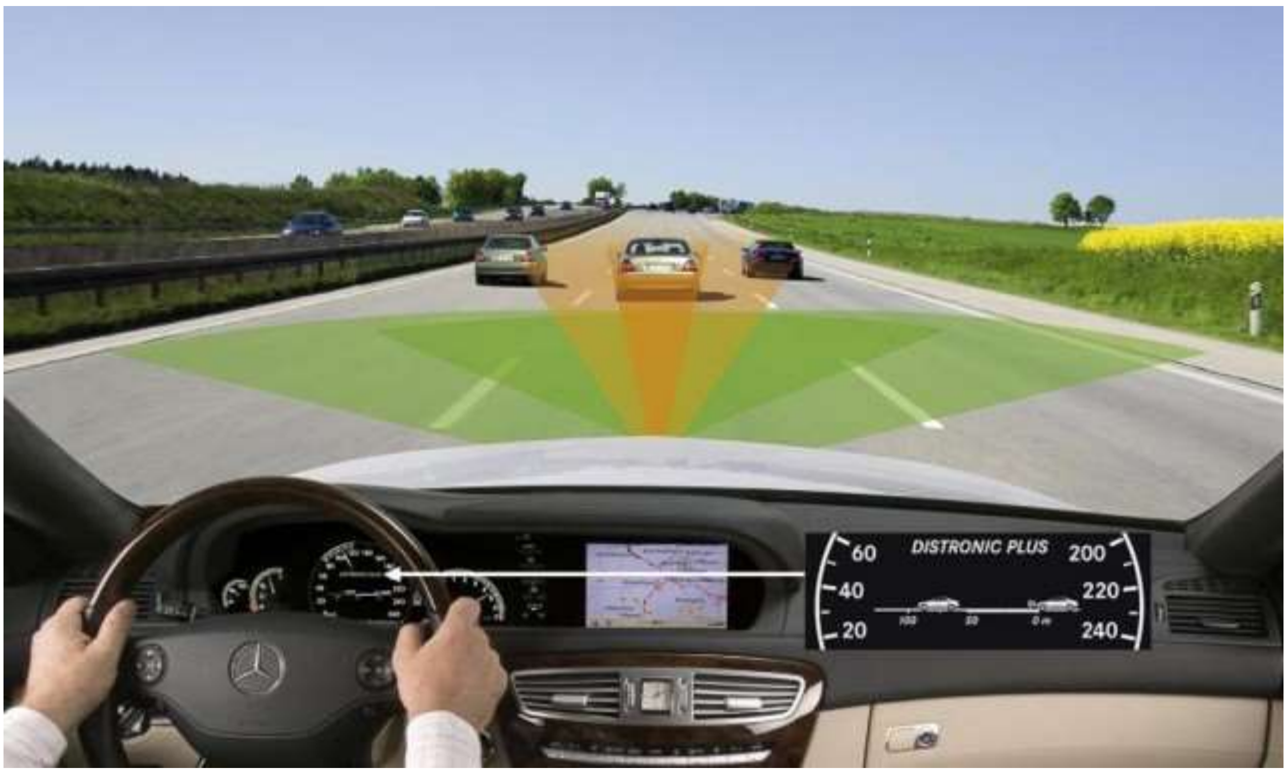
Here at Extreme Tech we see automobiles as much more than just four wheels, an engine, and a few seats. We view automobiles as being the ultimate mobile technology platform and something as worthy of our attention as the latest CPU or smartphone. With that in mind, we'll be releasing a series of introductory auto tech articles, providing readers with in-depth explanations of today's important technologies. First up for the series: adaptive cruise control.

Adaptive cruise control basics

Adaptive cruise control (ACC) is an intelligent form of cruise control that slows down and speeds up automatically to keep pace with the car in front of you. The driver sets the maximum speed — just as with cruise control — then a radar sensor watches for traffic ahead, locks on to the car in a lane, and instructs the car to stay 2, 3, or 4 seconds behind the person car ahead of it (the driver sets the follow distance, within reason). ACC is now almost always paired with a pre-crash system that alerts you and often begins braking.

ACC is ideal for stop-and-go traffic and rush hour commuting that swings from 60 mph to a standstill. Adaptive cruise control as of 2013 ranges from $2,500 at the high end to as little as $500. Less costly "partial ACC" only works at speeds of 20 or 25 mph and up, but it's markedly cheaper.

Expect to pay $2,000-$2,500 for full-range adaptive cruse control, but the price is coming down. The first ACC systems were about $2,800 five years ago.



Adaptive cruise control is also called active cruise control, autonomous cruise control, intelligent cruise control, or radar cruise control. This is the case because distance is measured by a small radar unit behind the front grille or under the bumper. Some units employ a laser, while Subaru uses an optical system based on stereoscopic cameras. Regardless of the technology, ACC works day and night, but its abilities are hampered by heavy rain, fog, or snow.

ACC is a crucial part of the self-driving cars of the near future. On an autonomous driving car, ACC needs to track the car in front but also cars in adjacent lens in case a lane change becomes necessary.

Adaptive cruise control is typically paired with forward collision warning that functions even if you don't have ACC engaged. When ACC is engaged, the car will typically slow under ACC braking at up to half its maximum braking potential. (Beyond that, driver and passenger discomfort with automated braking sets in.) Red lights flash at the driver (as with the Ford Taurus pictured above), the words "Brake!" or "Brake Now!" show on the instrument panel or head-up display, and a loud chime sounds. When ACC isn't engaged, it's still tracking traffic in front and intervenes with the warnings if it senses a potential accident.

Using ACC

To use adaptive cruise control, you start the same as you would with standard cruise control. The driver turns ACC on, accelerates to the desired speed, then presses the "Set" button. It's then possible to tweak the "+" and "-" buttons to raise or lower the speed, typically by in 1 or 5 mph increments. Lastly, the driver can set the desired gap behind the next car, most commonly by pressing a button to cycle among short, medium, and long following distances. Some automakers show icons with 1, 2 or 3 distance bars between two vehicle icons. Others, such as Merecedes-Benz, show the following distance in feet, though it's really in seconds of following gap translated to feet — for example, 200 feet of following distance at 60 mph (88 feet per second) is about 3 seconds.

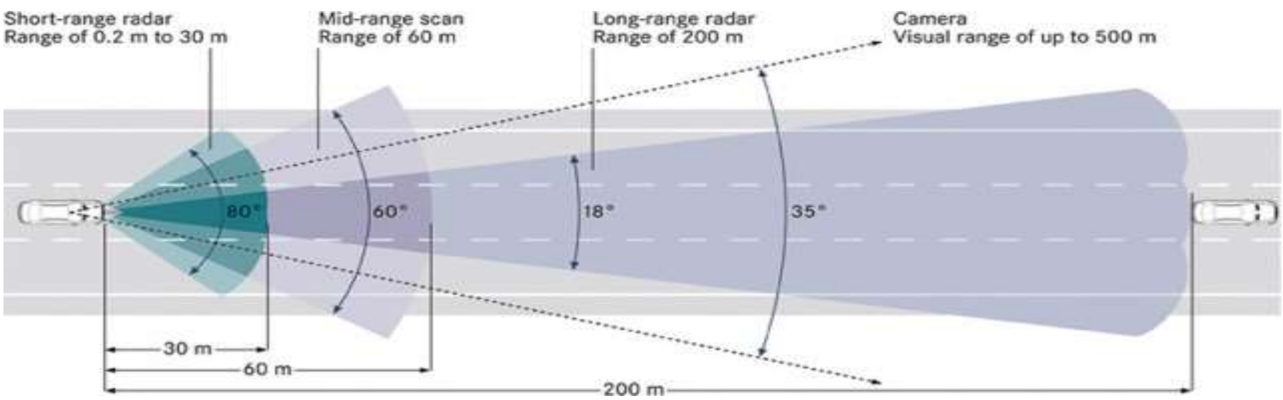
An indicator in the instrument panel or head-up display shows a car icon and often what looks like converging-at-infinity lines, indicating the roadway. When radar detects a car ahead, a second car icon appears or the lone car icon changes color.

When you're just starting out in a newly acquired car with ACC, start with the longest following distance. If you set the closest following distance, you'll get nervous if the following distance seems to get dangerously close and you're not sure if ACC is actually working. Most likely it is working and the driver may have lightly brushed the brake pedal, didn't realize it, and now ACC is available but not engaged.

THE TECHNOLOGY BEHIND ACC

Adaptive cruise control typically uses radar in a frequency band that doesn't compete with police radar and doesn't trigger radar detectors. For full-range ACC, some automakers use two radars — one for close range out to about 100 feet and a second that sees out to about 600 feet, or about 6-7 seconds at highway speeds. Partial ACC is usually a single unit, while some full-range ACC implementations are now able to use a single radar as well.

Early ACC units were a competing mix of laser on some cars and radar on the others. Radar won out because it works better in bad weather and costs came down to be competitive with laser. Even so, some ACC is optical. Subaru uses two cameras flanking the rear view mirror for its EyeSight system. It also provides unassisted automatic braking at low speeds if a pedestrian or stopped car gets in your path.



The effectiveness of even radar-based ACC is compromised in bad weather. In heavy rain or snow, it will shut off (you get a warning) or if the sensor in the grille or under the bumper is caked with snow or dirt.

So far, adaptive cruise control doesn't adjust to changing speed limits. Technology exists to do that: speed limit info is in navigation system map data, and lane departure warning cameras have the ability to read speed limit signs. In theory, you could tell ACC that at highway speeds you want your top speed to be the posted limit plus 5 mph. Then when you hit a construction zone posted for 45 mph, you'll stay reasonably close to the limit.

Is adaptive cruise control worth it?

Adaptive cruise control makes sense as the price comes down and as you drive more highway miles, especially long trips where your reflexes are dulled from driving five to 10 hours. For that, even partial ACC is helpful, and at $500-$1,000 on a $30,000 car (the typical selling price now), it could be worthwhile. If your commute involves freeways that are clogged every day, then you want full-range ACC for convenience.

The same holds if your long vacation or weekend trips involve leaving and returning big urban areas. Anyone who's driven Boston to Cape Cod on Friday night knows the pain. Returning to metro New York, Los Angeles, or Chicago, traffic starts slowing down 100 miles away on a Sunday night. Here, adaptive cruise control is a quality of life feature — just hit the "Set Speed" button and don't worry about cars stopping suddenly or creeping along.

While ACC is a great feature, I advise buyers to get lane departure warning and blind spot detection before you spend money on adaptive cruise control. These two features cost less and do more for you on most trips.

And keep in mind, vecause it's so complex, you have to order a car with ACC. You can't go to the parts department and order it added later on.