NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
(Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University, Kerala)

DEPARTMENT OF MECHATRONICS ENGINEERING

COURSE MATERIALS

MR 202 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 Dr. 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.

COURSE OUTCOME

After the completion of the course the student will be able to

SUBJECT CODE: C213	
COURSE OUTCOMES	
CO 1	Acquire knowledge on hydraulic system
CO 2	Understand about the concepts of pneumatic system
CO 3	Describe concepts of NC system
CO 4	Identify the concepts of fluid control system
CO 5	Acquire knowledge on working of different compressors
CO 6	Understand the concept and working of control valves

CO VS PO'S AND PSO'S MAPPING

CO Vs PO														
SUBJECT														
COURSE COUTCOME	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12	PSO1	PSO2
CO 1	3	3	2	2	-	-	-	-	-	-	2	3	3	2
CO 2	3	3	2	2	-	-	-	-	-	-	2	3	3	2
CO 3	3	3	2	2	-	-	-	-	-	-	2	3	3	2
CO 4	3	3	2	2	-	-	-	-	-	-	2	3	3	2
CO 5	3	3	2	2	-	-	-	-	-	-	2	3	3	2
CO 6	3	3	2	2	-	-	-	-	-	-	2	3	3	2

Note: H-Highly correlated=3, M-Medium correlated=2, L-Less correlated=1

SYLLABUS

Module 1

Industrial Prime movers-brief comparison of electrical, hydraulic and pneumatic systems hydraulic pumps-pressure regulation-gear pump- lobe pump- unbalanced and balanced type vane pump-variable displacement vane pump-radial piston pump-piston pump with stationary cam and rotating block-axial pump with swash plate-bent axis pump combination pumps-loading valves-filters and location of filters-full flow filter-proportional flow filter-edge type filter.

Module 2

Compressors-single cylinder compressor- double acting compressor and two stage compressor-combined two stage compressor-diaphragm compressor-screw compressor-rotary compressor-liquid ring compressor –lobe compressor-non positive displacement compressor-air receiver and compressor control-receiver pressure control via motor start stop –receiver pressure control using compressor outlet valve and inlet valve-stages of air treatment –filters-air driers-deliquescent and adsorption driers-lubricators-types of pressure regulators-relief-valves-non relieving pressure regulator-relieving pressure Regulator-service units.

Module 3

Control valves-graphic symbols –Types of control valves- simple 2/2 poppet valve-3/2poppet valve 4/2 poppet valve- spool valves- two way and four way spool valves-three position four way valve- pilot operated 3/2 valve-rotary valve-Check valve-simple check valve-right angle check valve-pilot operated check valve-restriction check valve-shuttle valve-fast exhaust valves-sequence valve-time delay valve-single stage infinite position valve-flapper jet servo valve

Module 4

Actuators-linear actuator-principle of operation-simple cylinder-cylinder with equal extend/ retract force-single acting cylinder-cylinder speed calculation-construction details of cylinder-cylinder cushioning-side load and stop tube-two stage telescopic piston-impact cylinder-mounting of cylinders- cylinder seals-static -anti extrusion rings-rotary actuators- constructional details-limited motion rotary actuators-Speed control of actuators-speed control by pump volume-meter in speed control-meter out speed control for overhauling load- bleed off speed control-pressure compensated flow control valve.

Module 5

Process control pneumatics - signals and standards - the flapper nozzle - volume booster - air relay and force balance - pneumatic controllers - proportional pneumatic control -n proportional plus integral pneumatic control - proportional plus integral plus derivative pneumatic control - Fail up and fail down actuators –Converters- PI and IP converters

Module 6

Controls in NC Machines and fluidic control - stepping motors - feedback devices- encoders - resolvers - inductosyn – tachogenerators - principles of fluid logic control –Coanda effect - basic fluidic devices - fluidic logic gates – bistable flipflop - OR and NOR gates - exclusive OR gates – fluidic sensors - backpressure sensor - cone jet proximity sensor - interruptible jet sensor.

QUESTION BANK

Q:NO	QUESTIONS	CO	KL	PAGE NO:
MODULE I				
1	Compare electrical, hydraulic and pneumatic systems?	CO1	K2	11
2	Illustrate Lobe pump?	CO1	K3	12
3	Illustrate gear pump?	CO1	K2	14
4	Explain about unbalanced and balanced type vane pump?	CO1	K3	15
5	Illustrate about variable displacement vane pump?	CO1	K2	15
6	With a neat sketch radial piston pump?	CO1	K2	18
7	Explain piston pump with stationary cam and rotating block?	CO1	K5	16
8	Illustrate loading valves?	CO1	K2	20
9	Explain the need of filter and its location?	CO1	K2	23
10	What is edge type filter?	CO1	K2	26
MODULE II				

1	Illustrate double acting compressor and two stage compressor?	CO2	K2	27
2	Illustrate diaphragm compressor	CO2	K2	28
3	Illustrate non positive displacement compressor?	CO2	K2	32
4	What is the significance of air receiver and compressor control?	CO2	K1	34
5	Illustrate screw compressor?	CO2	K1	36
6	How receiver pressure is controlled via motor start and stop?	CO2	K3	37
7	Explain about services units?	CO2	K2	40
8	Explain the significance of lubricators?	CO2	K2	42
9	Illustrate liquid ring compressor?	CO2	K2	47
10	Illustrate relieving pressure Regulator	CO2	K3	53
MODULE III				
1	Illustrate control values?	CO3	K3	55
2	Explain Types of control valves?	CO3	K3	56
3	Illustrate simple 2/2 poppet valve?	CO3	K2	58
4	Illustrate 3/2poppet valve?	CO3	K3	59
5	Illustrate 4/2 poppet valve?	CO3	K5	60
6	Explain the significance of three position four way valve?	CO3	K3	62
7	Explain the significance pilot operated 3/2 valve?	CO3	K2	64
8	Illustrate Check valve?	CO3	K1	66
9	Explain the significance simple check valve?	CO3	K1	67

10	Explain the significance right angle check valve?	CO3	K2	68
11	Illustrate fast exhaust valves?	CO3	K1	70
12	Illustrate time delay valve?	CO3	K2	71
13	Illustrate single stage infinite position valve?	CO3	K1	72
MODULE IV				
1	Explain the significance of actuators?	CO4	K2	76
2	Explain the cylinder with equal extend/ retract force-single acting cylinder?	CO4	K1	77
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4	Illustrate cylinder speed calculation?	CO4	K3	80
5	Illustrate construction details of cylinder?	CO4	K1	79
6	Illustrate cylinder cushioning?	CO4	K2	83
7	illustrate Speed control of actuators?	CO4	K2	84
8	How we use speed control by pump volume?	CO4	K2	85
9	Explain meter in speed control?	CO4	K2	86
10	Explain bleed off speed control?	CO4	K2	89
MODULE V				
1	Explain Process control pneumatics?	CO5	K2	90
2	Illustrate the flapper nozzle?	CO5	K2	92
3	Illustrate volume booster?	CO5	K3	93
4	How can we relate air relay and its force balance?	CO5	K2	94

5	What are pneumatic controllers?	CO5	K3	98
6	What is proportional pneumatic control?	CO5	K2	100
7	Illustrate Converters?	CO5	K2	102
8	Illustrate PI and IP converters?	CO5	K3	105
9	Explain proportional plus integral plus derivative pneumatic control?	CO5	K3	107
MODULE VI				
1	Explain stepping motors? And its types?	CO6	K1	108
2	Explain about commonly used feedback devices?	CO6	K2	109
3	How encoders work?	CO6	K2	112
4	Illustrate resolvers with neat sketch?	CO6	K3	125
5	What is inductosyn? Explain with clean neat sketch?	CO6	K2	120
6	What is tachogenerators?	CO6	K2	118

APPENDIX 1

CONTENT BEYOND THE SYLLABUS

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MODULE 1

BRIEF COMPARISON OF ELECTRICAL, HYDRAULIC AND PNEUMATIC SYSTEMS.

BASIC PNEUMATIC SYSTEM

- Pneumatic systems use pressurized air to make things move. Basic pneumatic system consists of an air generating unit and an air-consuming unit.
- Air compressed in compressor is not ready for use as such, air has to be filtered, moisture present in air has to be dried, and for different applications in plant pressure of air has to be varied.
- Several other treatments are given to the air before it reaches finally to the Actuators

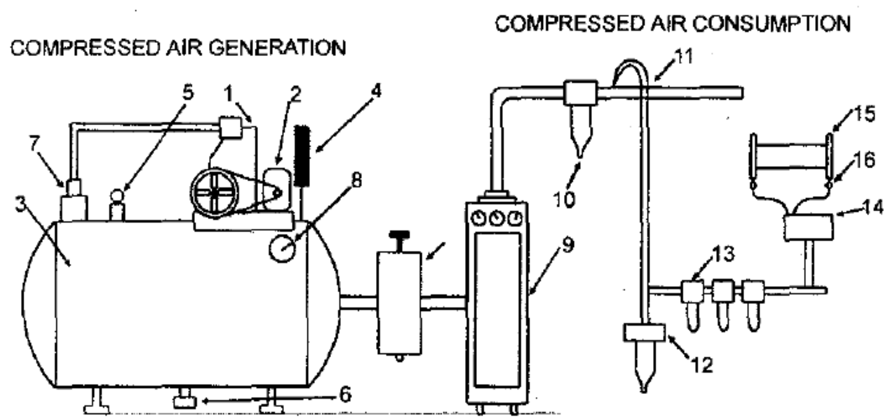


Fig. 2.1. Basic Pneumatic System

1. Compressor
2. Electric motor
3. Air receiver
4. Pressure switch
5. Safety valve
6. Auto drain
7. Check valve
8. Pressure gauge
9. Air dryer
10. After filter
11. Tapping
12. Auto Drain
13. Air service unit
14. Direction control valve
15. Actuator
16. Speed controller.

HYDRAULIC MOTOR

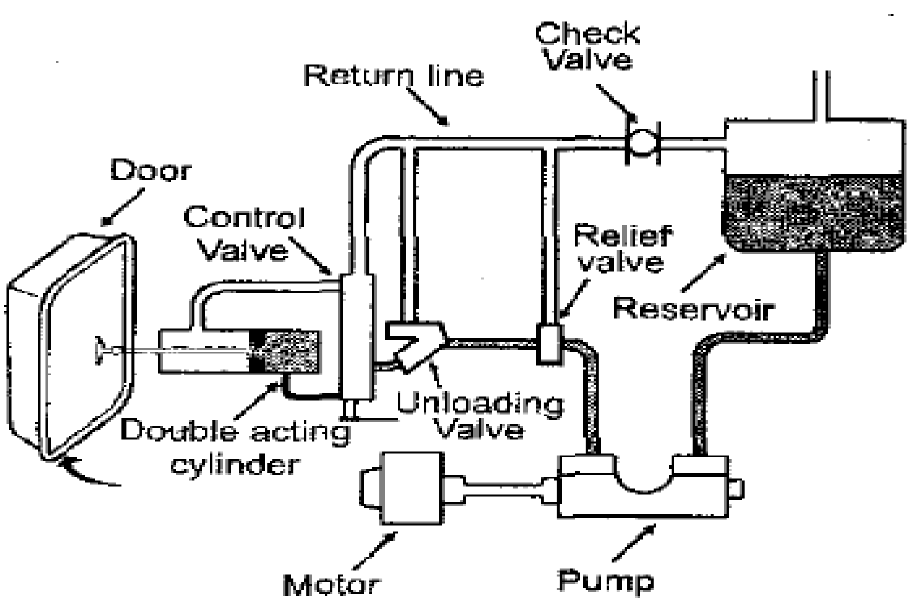
- Electric Motor Electric motor is used to drive the compressor Hydraulic Pump.
- Hydraulic pumps convert mechanical energy from a prime mover (engine or electric motor) into hydraulic (pressure) energy. The pressure energy is used then to operate an actuator Pumps push on a hydraulic fluid and create flow.
- Strainers and Filters. To keep hydraulic components performing correctly, the hydraulic

liquid must be kept as clean as possible.

- Foreign matter and tiny metal particles from normal wear of valves, pumps, and other components are going to enter a system.
- Strainers, filters, and magnetic plugs are used to remove foreign particles from a hydraulic liquid and are effective as safeguards against contamination Strainers.
- A strainer is the primary filtering system that removes large particles of foreign matter from a hydraulic liquid.
- Even though its screening action is not as good as a filter's, a strainer offers less resistance to flow.

ADVANTAGES

- Through the use of simple devices, an operator can readily start, stop, speed up, slow down, and control large forces with very close and precise tolerance.
- High power output from a compact actuator.
- Hydraulic power systems can multiply forces simply and efficiently from a fraction of an ounce to several hundred tons of output.
- Force can be transmitted over distances and around corners with small losses of efficiency.
- There is no need for complex systems of gears, cams, or levers to obtain a large mechanical advantage



A typical Hydraulic power system includes the following components:

1. Electric motor
2. Hydraulic pump
3. Filter
4. Pressure gauge
5. Pressure Regulator/Unloading valve
6. Pressure relief valve
7. Direction control valve
8. Hydraulic actuator
9. Load
10. Check valve
11. Reservoir
12. Manifolds, hose, tube, fittings, couplings, etc.

DISADVANTAGES

- System components must be engineered to minimize or preclude fluid leakage.
- Protection against rust, corrosion, dirt, oil deterioration, and other adverse environment is very important.
- Maintenance of precision parts when they are exposed to bad climates and dirty-atmospheres.
- Fire hazard if leak occurs.
- Adequate oil filtration must be maintained

APPLICATION OF HYDRAULIC ACTUATORS

- Used to drive the spray coating robots
- Used in heavy part loading robots
- Useful in material handling robot system
- Used to drive the joints of assembly (heavy) robots
- Useful in producing translator motion in Cartesian robot
- Useful in robots operating in hazardous, sparking environments.
- Useful in gripper mechanisms

DC SERVO MOTOR

PRINCIPLE

- A rotational movement is produced in a rotor when an electric current flows through the windings of the armature setting up a magnetic field opposing the field set up by the magnets.

THE MAIN COMPONENTS

- Rotor, stator, brush and commutator assembly. The rotor has got windings of armature and the stator has got the magnet. The brush and the commutator assemblies switch the current to the armature maintaining an opposed field in the magnets
- Types of electric drive

THE MOST COMMONLY

1. **DC SERVO MOTOR**
2. **AC SERVO MOTOR**
3. **STEPPER MOTOR**

DC Servo Motors	*AC Servo Motors*	*Stepper Motors*
• Higher power to weight ratio.	• Rotor is a permanent magnet and stator is housing the winding.	• Moves in known angle of rotation.
• High acceleration.	• No commutators and brushes.	• Position feed back is not necessary.
• Uniform torque.	• Switch is due to AC but not by commutation.	• Rotation of the shaft by rotation of the magnetic field.
• Good response for better control.	• Fixed nominal speed.	• Needs microprocessor circuit to start.
• Reliable, sturdy and powerful.	• Favourable heat dissipation	• Used in table top robots.
• Produces sparks in operation, not suitable for certain environments.	• More powerful.	• Finds less use in industrial robots.
	• Reversibility of rotation possible.	• Extensive use is robotic devices.

HYDRAULIC PUMPS-PRESSURE REGULATION

The sole purpose of a pump in a hydraulic system is to provide flow. A pump, which is the heart of a hydraulic system, converts mechanical energy, which is primarily rotational power from an electric motor or engine, into hydraulic energy. While mechanical rotational power is the product of torque and speed, hydraulic power is pressure times flow. The pump can be designed in such a way that either flow or pressure is fixed, while the other parameter is allowed to swing with the load. In other words, by fixing the pump flow, the pressure goes up as the load restriction is increased. Conversely, the flow goes down with an increase in load restriction when the pump delivers fixed pressure.

The pumping action is the same for every pump. Due to mechanical action, the pump creates a partial vacuum at the inlet. This causes the atmospheric pressure to force the fluid into the inlet of the pump. The pump then pushes the fluid into the hydraulic system the pump contains two check valves. Check valve 1 is connected to the pump inlet and allows fluid to enter the pump only through it. Check valve 2 is connected to the pump discharge and allows fluid to exit only through it.

When the piston is pulled to the left, a partial vacuum is created in the pump cavity 3. This vacuum holds the check valve 2 against its seat and allows atmospheric pressure to push the fluid inside the cylinder through the check valve 1. When the piston is pushed to the right, the fluid movement closes check valve 1 and opens outlet valve 2. The quantity of fluid displaced by the piston is forcibly ejected from the cylinder. The volume of the fluid displaced by the piston during the discharge stroke is called the displacement volume of the pump.

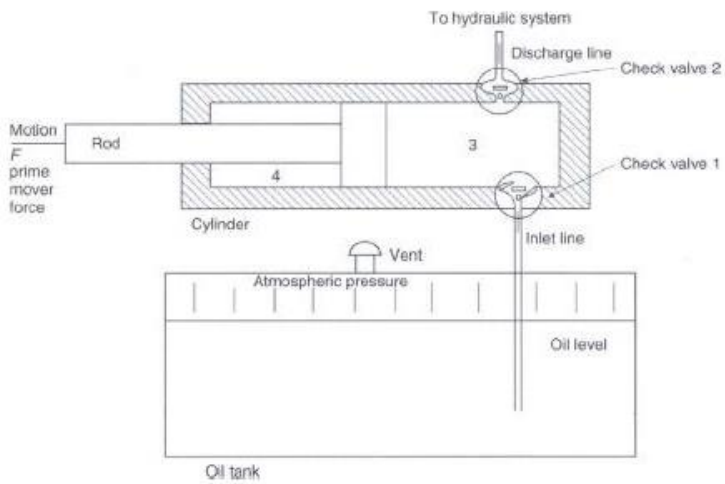
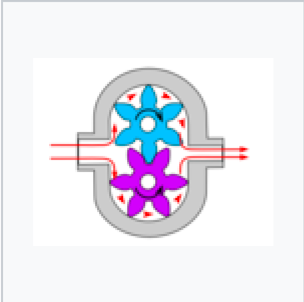
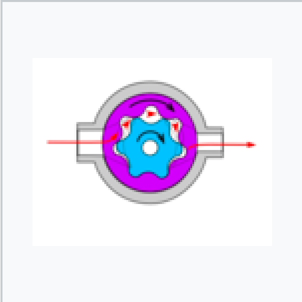
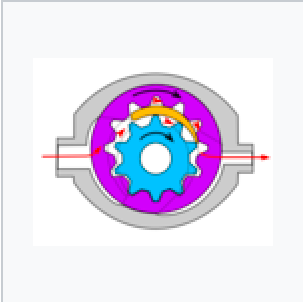


Figure 3.1
Pumping action of a simple piston pump

GEAR PUMP

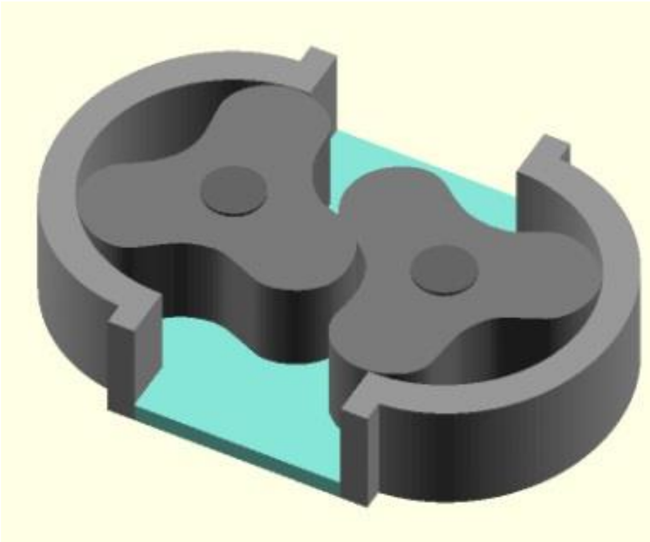
A **gear pump** uses the meshing of gears to pump fluid by displacement. They are one of the most common types of pumps for hydraulic fluid power applications. The gear pump was invented around 1600 by Johannes Kepler.

Gear pumps are also widely used in chemical installations to pump high viscosity fluids. There are two main variations: external gear pumps which use two external spur gear, and internal gear pumps which use an external and an internal spur gears (internal spur gear teeth face inwards, see below). Gear pumps are positive displacement (or fixed displacement), meaning they pump a constant amount of fluid for each revolution. Some gear pumps are designed to function as either a motor or a pump.

		
External gear pump design for hydraulic power applications.	Internal gear (Gerotor) pump design for automotive oil pumps.	Internal gear (Crescent Internal Gear) pump design for high viscosity fluids.

LOBE PUMP

These pumps offer different characteristics like an excellent high efficiency, rust resistance, hygienic qualities, reliability, etc. These pumps can handle high thickness fluids & solids without hurting them. The working of these pumps can be related to gear pumps, apart from the lobes which do not approach into contact by each other. Additionally, these pumps have superior pumping rooms compare with gear pumps that allow them to move slurries. These are made with stainless steel as well as extremely polished.



UNBALANCED AND BALANCED TYPE VANE PUMP

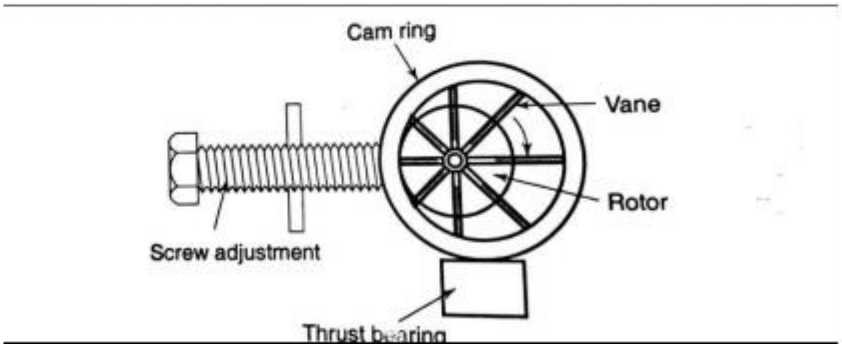
A **rotary vane pump** is a positive-displacement pump that consists of vanes mounted to a rotor that rotates inside a cavity. In some cases these vanes can have variable length and/or be tensioned to maintain contact with the walls as the pump rotates. It was invented by Charles C. Barnes of Sackville, New Brunswick, who patented it on June 16, 1874. There have been various improvements, including a variable vane pump for gases (1909) They are considered less suitable than other vacuum pumps for high-viscosity and high-pressure fluids, and are complex to operate. They can endure short periods of dry operation, and are considered good for low-viscosity fluids.

vane pumps are commonly used as high-pressure hydraulic pumps and in automobiles, including supercharging, power-steering, air conditioning, and automatic-transmission pumps. Pumps for mid-range pressures include applications such as carbonators for fountain soft-drink dispensers and espresso coffee machines. Furthermore, vane pumps can be used in low-pressure gas applications such as secondary air injection for auto exhaust emission control, or in low-pressure chemical vapor deposition systems.

Rotary-vane pumps are also a common type of vacuum pump, with two-stage pumps able to reach pressures well below 10^{-6} bar. These vacuum pumps are found in numerous applications, such as providing braking assistance in large trucks and diesel-powered passenger cars (whose engines do not generate intake vacuum) through a braking booster, in most light aircraft to drive gyroscopic flight instruments, in evacuating refrigerant lines during installation of air conditioners, in laboratory freeze dryers, and vacuum experiments in physics. In the vane pump, the pumped gas and the oil are mixed within the pump, and so they must be separated externally. Therefore, the inlet and the outlet have a large chamber, maybe with swirl, where the oil drops fall out of the gas. Sometimes the inlet has a venetian blind cooled by the room air (the pump is usually 40 K hotter) to condense cracked pumping oil and water, and let it drop back into the inlet. When these pumps are used in high-vacuum systems (where the inflow of gas into the pump becomes very low), a significant concern is contamination of the entire system by molecular oil back streaming.

VARIABLE DISPLACEMENT VANE PUMP

Variable displacement vane pumps are used in a variety of applications, most prominently in the context of modern automotive vehicles. They provide a means to react to changing consumer needs for oil flow and thereby to save energy. Despite their great practical relevance, minimal models capturing the main dynamic effects of such pumps have remained scarce. In this paper, a contribution is made in the form of a minimal model taking into account the force effects from line pressure exposure and dead volume compression and expansion. The thus-obtained pump model is autonomous and allows for a simple integration in simulation models. For a classic circuit with pressure regulation, a circuit model featuring the variable displacement vane pump model is developed for which simulation results are presented.



Working: The rotor containing the vanes is positioned eccentric or off-center with regard to cam ring by means of the adjusting screw hence when the rotor is rotated, in increasing and decreasing volume can be created inside the cylinder bore. If the screw is adjusted slightly so that the eccentricity of the rotor to the cam ring is not sufficient the flow will be less where as with higher eccentricity the delivery volume will be increased with the screw adjustment back completely out the cam ring naturally centers with a rotor and no pumping will be the eccentricity will be zero.

RADIAL PISTON PUMP

radial piston pump is a type of hydraulic piston pump. The working pistons extend in a radial direction symmetrically around the shaft, marking the main difference beween them and another piston pump, the axial piston pump, which has axially rotating pistons.

Radial piston pumps arrange a series of pistons radially in a cylindrical block around a rotor hub. The block consists of a pintle, a cylinder barrel with pistons, and a rotor. The pintle directs the fluid in and out of the cylinder. The rotor, mounted eccentrically in the pump housing, forces the pistons in and out of cylinders as it rotates, which cause hydraulic fluid to be sucked into the cylinder cavity and then be discharged from it. Inlets and outlets for the pump are located in a valve in a central hub. Each piston is connected to inlet port when it starts extending while it is connected to the outlet port when start retracting.

An alternative design places inlets and outlets around the perimeter of the pump housing. Radial piston pumps can be purchased as fixed- or variable-displacement models. In the variable-displacement version, the eccentricity of the rotor in the pump housing is altered to decrease or increase the stroke of the pistons.

They have many advantages, such as high efficiency, high-pressure capability up to 1,000 bar or 14000 psi, low flow and pressure ripple, low noise level, very high load at the lowest speed, and high reliability. A disadvantage is that they are bigger than axial pumps, because of the bigger radial dimensions, and so cannot always be used in applications with space constraints.

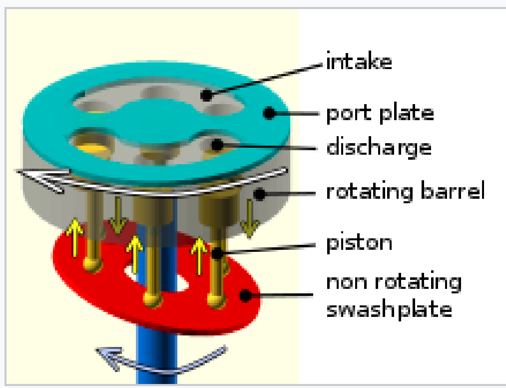
PISTON PUMP WITH STATIONARY CAM AND ROTATING BLOCK- AXIAL PUMP WITH SWASH PLATE

An axial piston pump has a number of pistons (usually an odd number) arranged in a circular array within a housing which is commonly referred to as a cylinder block, rotor or barrel. This cylinder block is driven to rotate about its axis of symmetry by an integral shaft that is, more or less, aligned with the pumping pistons (usually parallel but not necessarily).

- **Mating surfaces**. One end of the cylinder block is convex and wears against a mating surface on a stationary valve plate. The inlet and outlet fluid of the pump pass through different parts of the sliding interface between the cylinder block and valve plate. The valve plate has two semi-circular ports that allow inlet of the operating fluid and exhaust of the outlet fluid respectively.
- **Protruding pistons**. The pumping pistons protrude from the opposite end of the cylinder block. There are numerous configurations used for the exposed ends of the pistons but in all cases they bear against a cam. In variable displacement units, the cam is movable and commonly referred to as a swash plate, yoke or hanger. For conceptual purposes, the cam can be represented by a plane, the orientation of which, in combination with shaft rotation, provides the cam action that leads to piston reciprocation and thus pumping. The angle between a vector normal to the cam plane and the cylinder block axis of rotation, called the cam angle, is one variable that determines the displacement of the pump or the amount of fluid pumped per shaft revolution. Variable displacement units have the ability to vary the cam angle during operation whereas fixed displacement units do not.
- **Reciprocating pistons**. As the cylinder block rotates, the exposed ends of the pistons are constrained to follow the surface of the cam plane. Since the cam plane is at an angle to the axis of rotation, the pistons must reciprocate axially as they process about the cylinder block axis. The axial motion of the pistons is sinusoidal. During the rising portion of the piston's reciprocation cycle, the piston moves toward the valve plate. Also, during this time, the fluid trapped between the buried end of the piston and the valve plate is vented to the pump's discharge port through one of the valve plate's semi-circular ports - the discharge port. As the piston moves toward the valve plate, fluid is pushed or displaced through the discharge port of the valve plate.
- **Effect of precession**. When the piston is at the top of the reciprocation cycle (commonly referred to as top-dead-center or just TDC), the connection between the trapped fluid chamber and the pump's discharge port is closed. Shortly thereafter, that same chamber becomes open to the pump's inlet port. As the piston continues to process about the cylinder block axis, it moves away from the valve plate thereby increasing the volume of the trapped chamber. As this occurs, fluid enters the chamber from the pump's inlet to fill the void. This process continues until the piston reaches the bottom of the reciprocation cylinder - commonly referred to as bottom-dead-center or BDC. At BDC, the connection between the pumping chamber and inlet port is closed. Shortly thereafter, the chamber becomes open to

the discharge port again and the pumping cycle starts over.

- **Variable displacement**. In a variable displacement pump, if the vector normal to the cam plane (swash plate) is set parallel to the axis of rotation, there is no movement of the pistons in their cylinders. Thus there is no output. Movement of the swash plate controls pump output from zero to maximum. There are two kinds of variable-displacement axial piston pumps:
  - Direct displacement control pump, a kind of axial piston pump with a direct displacement control. A direct displacement control uses a mechanical lever attached to the swash plate of the axial piston pump. Higher system pressures require more force to move that lever, making direct displacement control only suitable for light or medium duty pumps. Heavy duty pumps require servo control A direct displacement control pump contains linkages and springs and in some cases magnets rather than a shaft to a motor located outside of the pump (thereby reducing the number of moving parts), keeping parts protected and lubricated and reducing the resistance against the flow of liquid.



Axial piston pump - 3D Render with the parts labeled

BENT AXIS PUMP COMBINATION PUMPS

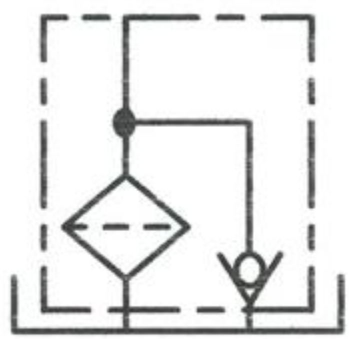
Bent axis pumps, axial piston pumps and motors using the bent axis principle, fixed or adjustable displacement exists in two different basic designs. The Thoma-principle (engineer Hans Thoma, Germany, patent 1935) with max 25 degrees angle and the Wahl mark-principle (Gunnar Axel Wahl mark, patent 1960) with spherical-shaped pistons in one piece with the piston rod, piston rings, and maximum 40 degrees between the driveshaft centerline and pistons (Volvo Hydraulics Co.). These have the best efficiency of all pumps. Although in general the largest displacements are approximately one litre per revolution, if necessary a two-liter swept volume pump can be built. Often variable-displacement pumps are used, so that the oil flow can be adjusted carefully. These pumps can in general work with a working pressure of up to 350–420 bars in continuous work

LOADING VALVES

loading valve is a type of valve which is designed to provide a fixed back pressure for the dosing pump to work against. Working against a fixed back pressure provides a number of advantages to many common dosing applications. For instance, when dosing into a pipeline, the pressure in the pipe can vary. To ensure that a dosing pump delivers a fixed volume of chemical reagent, the pressure must be stable because when the pipe pressure / back pressure varies, the corresponding volume of reagent delivered by the pump will also vary. So by fitting a loading valve and fixing the back pressure, we can ensure that each stroke of the dosing pump delivers the same displacement of chemical reagent. This is particularly crucial in chlorine dosing applications within water treatment processes. Another benefit of using loading valves is that they prevent syphoning through the dosing pump. This is important when the physical setup of a dosing system can result in the syphoning effect. Each of our multi-function valves includes a loading valve function. We also offer our **10400 range of adjustable loading valves**, which result in very precise control of the back pressure that the pump is working against.

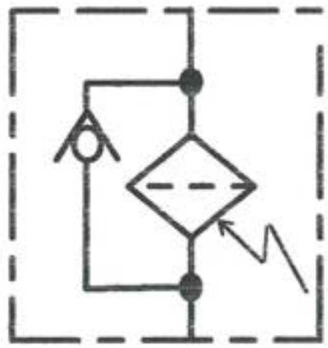
FILTERS AND LOCATION OF FILTERS

Contaminated fluid causes most hydraulic system failures. Oil in a reservoir may look clean to the naked eye, but silt contamination particles too small to see can still wreck pumps, cause valves to stick, and erode cylinder bores. In many facilities, components may take the blame for problems in error, when contaminated fluid is the culprit. It is amazing that some plants will change pumps every six months (believing that is normal component life when they could add a proper filtration system and get many times longer pump service life.



A well-filtered hydraulic system should not have particles in the fluid larger than 10 microns. (A micron is 0.000039 inches.) A contamination particle that measures 0.001 in. across is 25 microns. The smallest dirt particle that is visible to the naked eye is 40 microns. Simply looking at an oil sample is not a good way to tell if the filters are cleaning the fluid**.**

Nominal or *absolute* are common terms found in hydraulic filter micron ratings. A filter with a nominal rating takes out most of the particles that measure the same size or larger than the stated micron size. A filter with an absolute rating takes out all particles the same size or larger than the rated micron size. A newer filter-rating system called the *beta ratio* is replacing the old nominal and absolute designations.



FULL FLOW FILTER

The strainers and filters used with Navy diesel engines are a part of what is generally referred to as the LUBRICATING OIL FIL-TERING SYSTEM. Currently, engines use a system known as the FULL-FLOW FILTER-ING SYSTEM. You should refer to figures 8-9 and 8-10 as you read the descriptions of this system.

In the full-flow filtering system, all the oil supplied to the engine by the oil pump normally passes through the filter elements, which remove impurities of 25 microns and larger.

NOTE: One micron is one millionth of a meter, or thirty-nine millionths of an inch. An ordinary grain of table salt is about 100 microns, and 25 microns is approximately one-thousandth of an inch.

There are only two conditions where unfiltered lubricating oil is supplied to the engine: (1) when the lubricating oil is cold (high viscosity), and (2) when the filter element is clogged. When one of these conditions exists, a bypass valve opens and a portion of the oil is bypassed around the filter element. The action of the bypass valve results from the resistance of the filter element to allow the oil to pass through it. The resistance creates enough back pressure for the spring-loaded bypass valve to open.

A secondary filtering system, which operates independently of the primary system, is currently being installed on various marine diesel engines.

PROPORTIONAL FLOW FILTER

Proportional flow hydraulic filter, as name suggest, will have capability to filter a portion of hydraulic fluid in one cycle. But due to continuous recirculation of hydraulic fluid in the system, complete hydraulic fluid will be filtered with proportional flow hydraulic filter

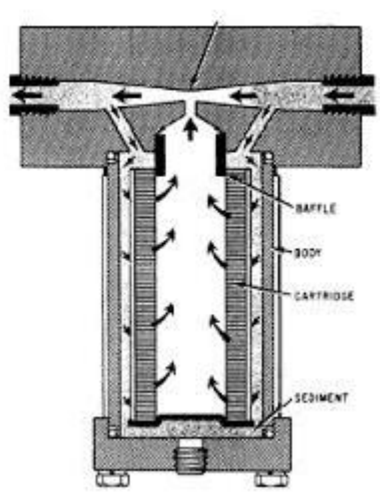
A portion of hydraulic fluid, which is going in to the system, will have to pass through a filtering element and therefore foreign particles and other tiny metal particles will be captured by the filtering element and filtered hydraulic fluid will return to the system via a passage provided to connect hollow core of filter with venturi throat.

LET US SEE HERE THE VARIOUS COMPONENTS OF A PROPORTIONAL FLOW HYDRAULIC FILTER

First of all we will see here the basic construction and components of a proportional flow hydraulic filter as mentioned here.

INLET PORT

In case of proportional flow hydraulic filter, filtering action will take place in either flow direction. Port from where a portion of hydraulic fluid will be sucked inside the filter, will be considered as inlet port and it is shown in following figure.



There are two passages for hydraulic fluid to enter in proportional flow filter as displayed in above figure.

FILTER HOUSING

Filter housing consist the filter element. Hydraulic fluid, which is going in to the system, will enter in to the filter housing and further hydraulic fluid will flow towards the venturi throat passing through the filter element i.e. towards outlet port.

FILTER ELEMENT

Filter element is a key component of any filter. Hydraulic fluid, which is going in to the system, will enter in to the filter housing and further hydraulic fluid will flow towards outlet port passing through the filter element. During flowing through the filter element, dirt and other foreign particles will be left over the outer surface of the filter element and filtered hydraulic fluid will further flow towards the system via outlet port.

OUTLET PORT

Filtered hydraulic fluid will flow back to the system via a passage connecting hollow core of filter with venture throat. Hence a point from where filtered hydraulic fluid leaves the proportional flow filter and returning back to the system will be termed as outlet port of proportional flow filter.

EDGE TYPE FILTER

Overview

This type of filter element utilizes stacks of paper discs tightly compressed on a tubular core to form a continuous cylindrical surface where contaminants are filtered at the edge of the cylinder.

Advantages

- Ability to capture very fine particles down to 1 micron.
- Back flushing can be particularly effective providing extended service life before element replacement, reducing costs associated with disposable filter media.
- Disadvantages
- Suitable only for oils without waxes or paraffin’s.
- Water based coolants or tramp water in oil based coolant will blind off the filter elements requiring replacement.
- Requires pressure vessel and filter pump and has the problems associated with back flushing type filter in general including the possibility of packing the filter vessel with porous swarf.
- Back flushed solids may be difficult to filter out for removal from system.
- High cost to purchase.
- High cost to replace filter elements when they no longer back flush effectively.

How It Works

This type of filter element utilizes stacks of paper discs tightly compressed on a tubular core to form a continuous cylindrical surface. Solid contaminants are deposited on the surface as liquid flows through the narrow passages between the paper discs. Particles down to one micron are deposited on the face of the paper stack. The stack can be effectively backwashed quite a number of times before the element needs to be replaced. The effectiveness of back flushing stacked paper discs is improved over other types of back flushing filters because the high flow resistance between the paper discs limits the back flow through any one area once the solids have been dislodged, promoting more uniform cleaning of the surface.

Stacked paper edge filters are generally suited only to oil filtration as the paper fibers swell and blind off when they absorb water. The introduction of tramp water to the machining oil from parts washing or chilling below the dew point of ambient plant air must be avoided. In addition, the choices of suitable oil are limited because long chain paraffin's, such as chlorinated extreme pressure additives in honing oils, are big enough to be captured by the element, permanently blinding off flow through the element, necessitating replacement. The filter manufacturer's recommendations of permissible oil this for type of equipment should be strictly followed.

The operating limitations and equipment complexities associated with back flushing type filters in general apply to back flushing paper disc edge filtration as well. These include:

- Machining operations must stop during back flushing.
- Systems equipped to provide continuous flow during back flushing requires both additional clean and dirty tank capacity, with the dirty tanks subject to significant settling of solids. The additional purchase and replacement cost of oil must be considered.
- The closed pressure vessel may have difficulty expelling solid contaminants, particularly contaminants that create a tightly packed porous cake such as steel or cast iron grinding swarf requiring shutdown and disassembly of the pressure vessel. The addition of first stage magnetic separators may reduce the frequency of packing the vessel but cannot eliminate this risk.
- The need to filter the back flushed solids for removal from the filter system. Typically a bag filter is used with liquid straining through by gravity. This limits the effective particle retention of the bag resulting in a significant percentage of contaminants being recycled within the filter system.

One of the most successful applications for filter of this type is filtering carbide solids from grinding oil. Overall, the high capital cost and complexity of this type of system is difficult to justify when compared to simple stacked disc cartridge type depth filters or vacuum filters utilizing high performance bulk roll filter media.

MODULE 2

MODULE - II (1)

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PNUEMATIC SYSTEM

→ Pneumatic technology deals with the study of behavior and applications of compressed air in our dialy life in general and manufacturing automation in particular.

→ Pneumatic systems use air as the medium which is abundantly available and can be exhausted into the atmosphere after completion of the assigned task.

BASIC COMPONENTS OF PNEUMATIC SYSTEM

A) Air filters:

→ These are used to filter out the contaminants from the air

B) Compressor

→ Compressed air is generated by using air compressors. Air compressors are either diesel or electrically operated. Based on the requirement of compressed air, suitable capacity compressors may be used.

c) Air Cooler

→ During compression operation, air temperature increases. Coolers are used to reduce the temperature of the compressed air.

d) Electric motor

transforms electrical energy into mechanical energy. it is used to drive the Compressor.

e) Separator

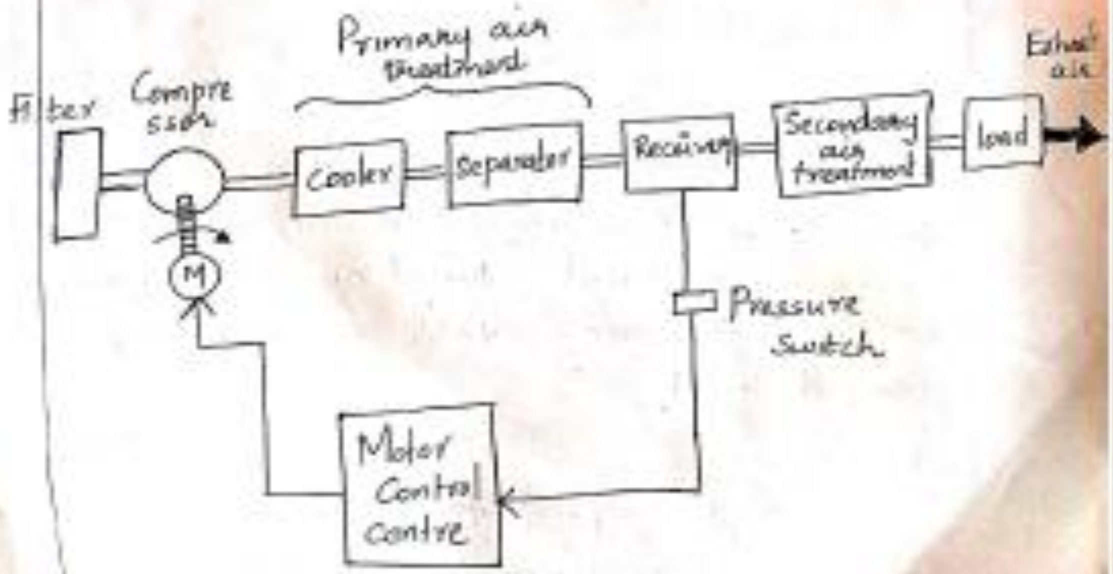
To remove the moisture content in the cooled air.

f) Receiver tank

The compressed air coming from the Compressor is stored in air receiver.

g) Secondary air treatment

To remove oil content and also remove moisture in air



Component Parts of pneumatic System

(2)

COMPRESSOR

→ It is a mechanical device which converts mechanical energy into fluid energy.

→ The compressor increases the air pressure by reducing its volume which also increase the the temperature of the compressed air.

→ The compressor is selected based on the pressure it needs to operate and the delivery volume.

→ The compressor can be classified into 2 main types:

1) Positive displacement compressor
2) Dynamic " "

Positive displacement compressors include piston type, vane type, diaphragm type and screw type.

PISTON COMPRESSORS:

① SINGLE CYLINDER COMPRESSOR

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→ piston Compressors are commonly used in pneumatic systems.

→ The Simplest form is Single cylinder Compressor

→ It produces one pulse of air per piston stroke

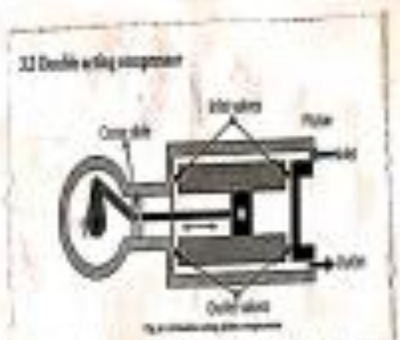
→ As the piston moves down during the Inlet stroke the Inlet valve opens and air is drawn into the cylinder.

→ As the piston moves up the Inlet valve closes and the exhaust valve opens which allows the air to be expelled.

→ The Valves are Spring loaded.

→ The Single cylinder Compressor gives Significant amount of pressure pulses at the Outlet port. The pressure developed is about 3-40 bar.

DOUBLE ACTING COMPRESSOR



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(5)

→ The pulsation of air can be reduced by using double acting compressor.

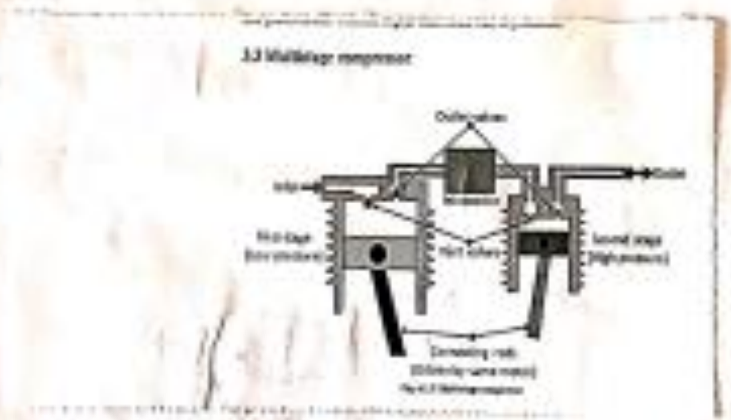
→ It has 2 sets of valves and a crosshead.

→ As the piston moves, the air is compressed on one side whilst on the other side of the piston, the air is sucked in.

→ Due to the reciprocating action of the piston the air is compressed and delivered twice in one piston stroke.

→ pressure higher than 30 bar can be produced.

TWO STAGE COMPRESSOR



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→ As the pressure of the air Increases, its temperature rises, it is essential to reduce the air temperature to avoid damage of Compressor and other mechanical elements.

→ The multistage / two stage Compressor with Intercooler in between is shown in figure.

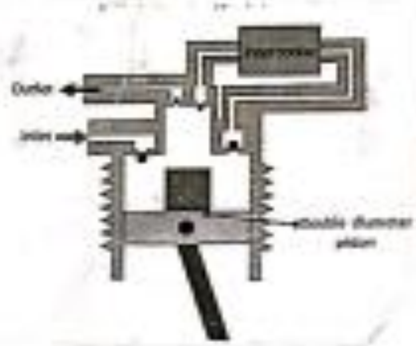
→ It is used to reduce the temperature of Compressed air during the Compression stages.

→ The Intercooling reduces the volume of air which used to Increase due to heat.

→ The Compressed air from 1st stage enters the Intercooler where it is cooled. This air is given as an Input to the 2nd stage where it is Compressed again.

→ It develop a pressure of around 50 bar.

COMBINED TWO STAGE COMPRESSORS



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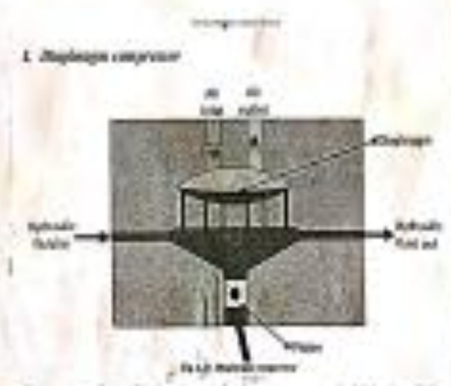
→ In this type, a stage compression is carried (4) out by using the same piston.

→ Initially when the piston moves down, air is sucked in through the inlet valve. During the compression process, the air moves out of the exhaust valve into the intercooler.

→ As the piston moves further the stepped head provided on the piston moves into the cavity thus causing the compression of air.

→ Then, this is let out by the exhaust port.

DIAPHRAGM COMPRESSOR



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→ These are small capacity compressors.

→ The piston reciprocates by a motor driven crankshaft.

→ As the piston moves down it pulls the hydraulic fluid down causing the diaphragm to move along and the air is sucked in.

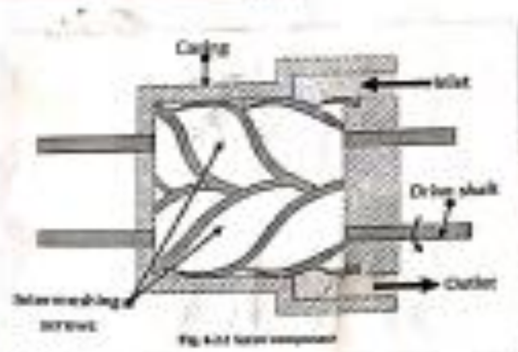
→ When the piston moves up the fluid pushes the diaphragm up causing the ejection of air from the outlet port.

→ Since the flexible diaphragm is placed in between the piston and the air, no contamination take place.

→ In piston compressors the lubricating oil from the piston walls may contaminate the compressed air. The contamination is undesirable in food, pharmaceutical and chemical industries.

→ Such application diaphragm compressors are used.

SCREW COMPRESSORS



(5)

→ Piston compressors are used when high pressures & relatively low volume of air is needed. The system is complex as it has many moving parts.
→ For medium flow and pressure applications, screws compressor can be used.
→ It is simple in construction with less number of moving parts.
→ The air delivered is steady with no pressure pulsation.
→ It has a meshing screws.
→ The air from the inlet is trapped between the rotating meshing screws and is compressed due to vane action.
→ The contact between the two meshing surface is minimum, hence no cooling is required.
→ The screws are synchronized by using external timing gears.

ROTATORY VANE COMPRESSORS

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→ The unbalanced vane compressor consists of spring loaded vanes seating in the slots of the rotor.
→ The pumping action occurs due to movement of

the Vanes along a cam ring.

→ The rotor is eccentric to the cam ring.

→ As the rotor rotates, the vanes follow the Inner Surface of the cam ring.

→ The Space between the Vanes decreases near the Outlet due to the eccentricity.

→ This causes Compression of the air. These Compressors are Free from pulsation. If the eccentricity is Zero no flow take place.

LIQUID RING COMPRESSOR

→ Liquid ring vane Compressor is a Variation of Vane Compressors.

→ The Casing is filled with liquid upto rotor center.

→ The air enters the Compressor through the distributor fixed to the Compressor.

→ During the Impeller rotation, the liquid will be Centrifuged along the inner ring of the casing to form the liquid ring.

→ There are 2 suction and discharge ports provided in

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in the distributor (6)

→ During the first quarter of cycle, the air is sucked in both suction chambers of the casing & during the second quarter of the cycle, the air is compressed & pushed out through the two discharge ports.

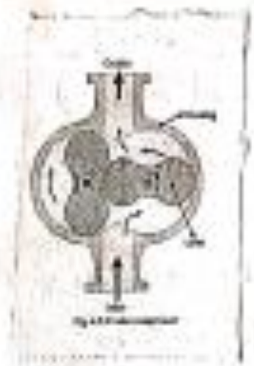
→ During the 3rd and 4th quarters of the cycle, the process is repeated.

→ This type of compressor has no leakage & has minimal friction.

→ For smooth operation, the rotation speed should be about 3000 rpm.

→ The delivery pressure is low (about 5 bar)

LOBE COMPRESSOR



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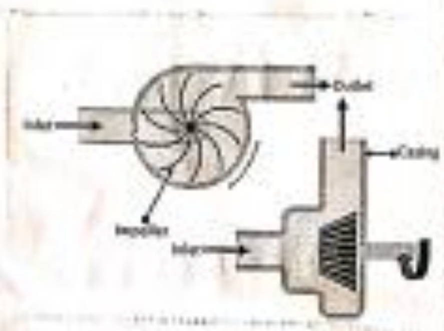
→ The lobe compressor is used when high delivery volume but low pressure is needed.

→ It consist of 2 lobes with one being driven and the other driving.

→ The construction is similar to lobe pump

→ The operating pressure is limited by leakage b/w rotors and housing. As the wear increases during the Operation, the efficiency falls rapidly.

DYNAMIC COMPRESSORS / NON-POSITIVE DISPLACEMENT COMPRESSORS (BLOWERS)



-> When very large volume of compressed air is required in applications such as Ventilators, Combustion system and pneumatic powder blower Conveyors, the dynamic Compressor can be used.

-> The pressure needed is very low in such appln's.

-> Figure shows a typical centrifugal type blower.

-> The Impeller rotates at a high speed.

-> Large volume of low pressure air can be provided by blowers.

-> The blowers draw the air in and the Impeller flings it out due to Centrifugal force.

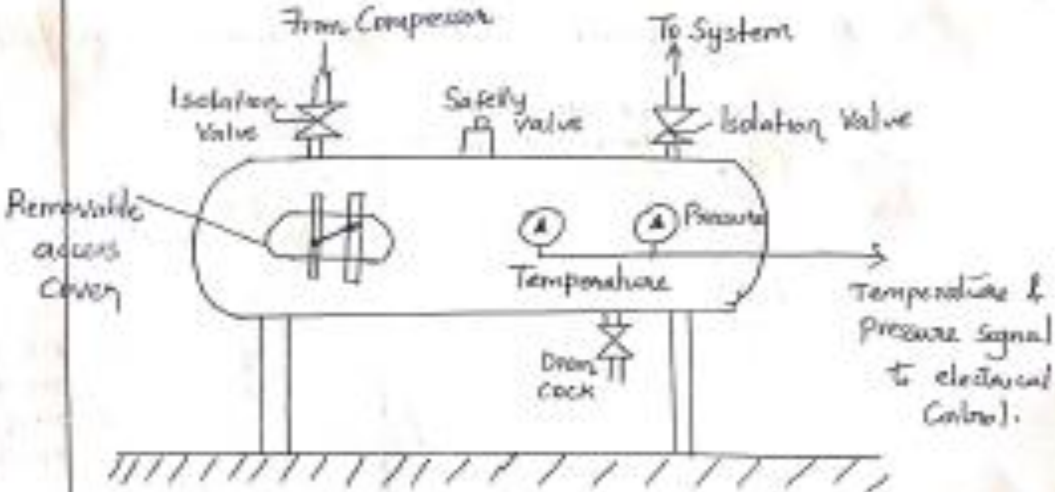
-> Positive displacement Compressor need oil to lubricate the moving parts, whereas the dynamic Compressors have no such needs

Air Receivers & Compressor Control

→ An air receiver is used to store high pressure air from the compressor.

→ Its volume reduces pressure fluctuations arising from changes in load and from compressor switching

→ Air coming from the compressor will be warm and the large surface area of the receiver dissipates this heat to the surroundings atmosphere. Any moisture left in the air from the compressor will condense out in the receiver, so outgoing air should be taken from the receiver top.



Compressed air receiver

→ In the figure, they are usually of cylindrical construction for strength

→ It also have a safety relief valve to guard

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against high pressure arising from failure of the pressure control scheme.

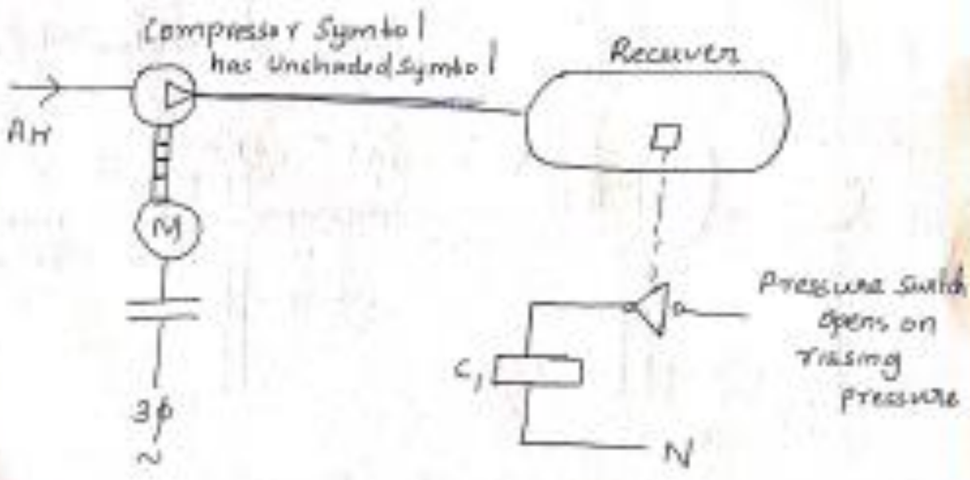
→ pressure indication and usually temperature indication are provided with pressure switches for control of pressure & high temperature switches for remote alarms.

→ A drain cock allows removal of condensed water, and access via manhole allows cleaning.

→ Removal of manhole cover is hazardous with a pressurised receiver and safety routines must be defined and followed to prevent accidents

COMPRESSOR CONTROL

① Receiver pressure control via motor start/stop:



Receiver pressure control via motor start/stop.

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→ Control of the compressor is necessary to maintain pressure in the receiver.

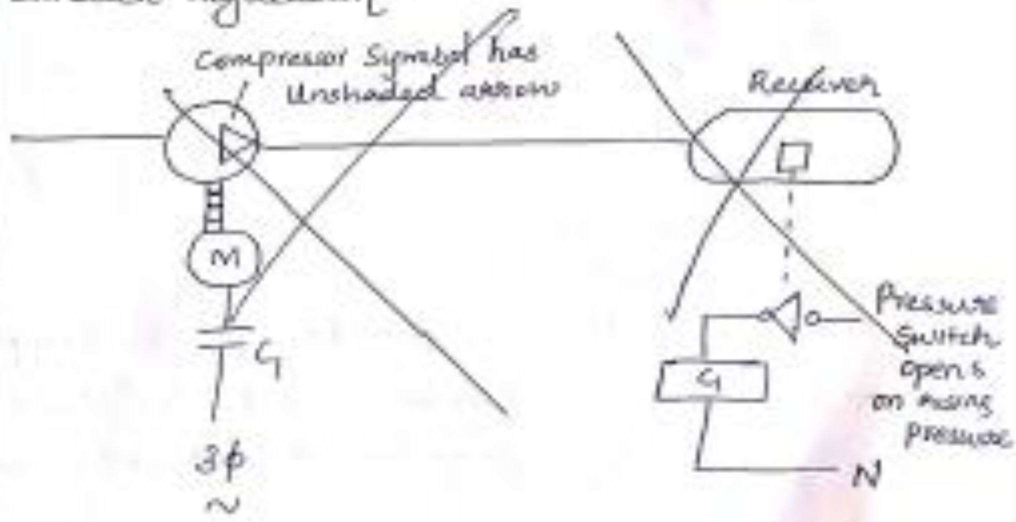
→ The simplest method of achieving this is to start compressor when receiver pressure falls to some minimum pressure, and stop the compressor when pressure rises to a satisfactory level again.

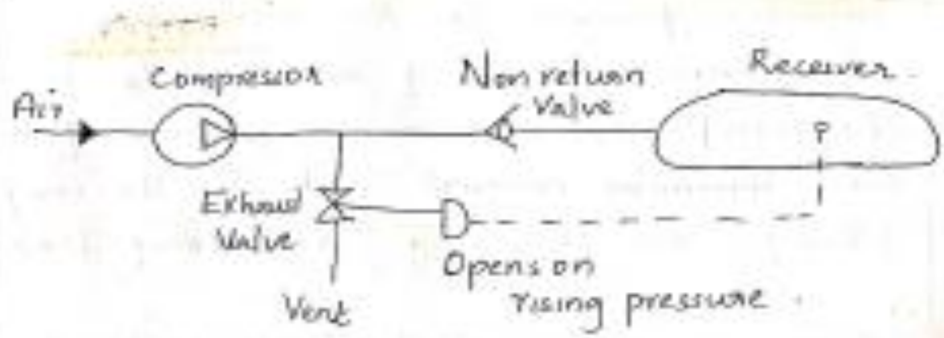
② Receiver pressure Control Using Compressor Outlet Valve:

→ When the compressor runs continuously and an exhaust valve is fitted to the compressor outlet.

→ This valve opens when the required pressure is reached.

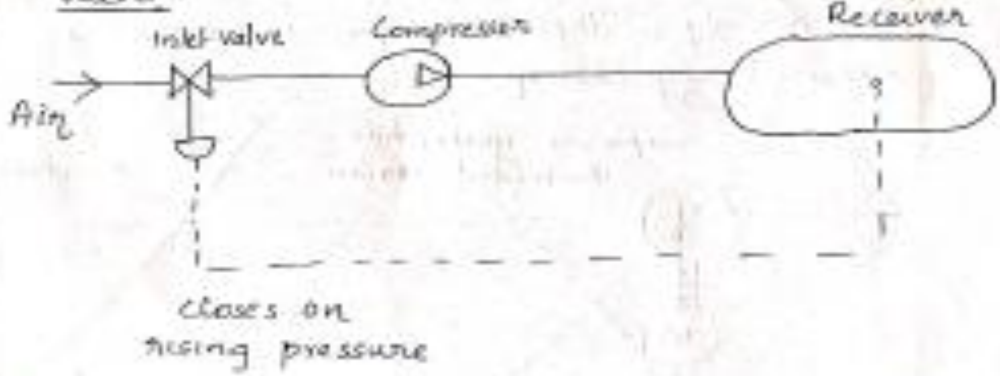
→ A non return valve prevents air returning from the receiver. This technique is known as exhaust regulation.





An exhaust Valve is provided between Compressor and receiver. When pressure in the receiver exceeds, the Valve opens and to went the air out from the Compressor.

(3) Receiver pressure Control using Compressor Inlet Valve.



→ An inlet Valve is provided for the Compressor.

→ Once the receiver pressure reaches the limit, the valve closes. So air doesn't enter inside

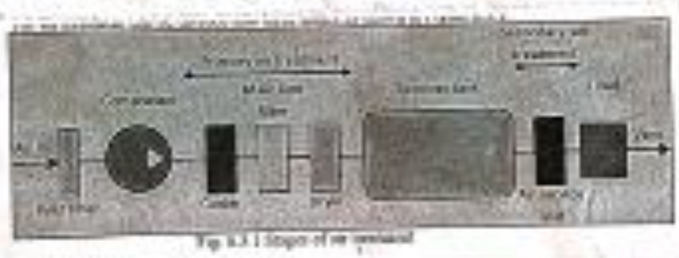
AIR TREATMENT STAGES :

→ Atmospheric air is contaminated with dust, smoke and is humid.

→ These particles can cause wear of the s/m components & presence of moisture may cause corrosion.

→ Hence it is essential to treat the air to get rid of these impurities

→ The air treatment can be divided into 3 stages.



STAGES OF AIR TREATMENT

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→ In the first stage, the large sized particles are prevented from entering the compressor by an intake filter

→ The air leaving the compressor may be humid and may be at high temperature.

→ The air from the compressor is treated in the second stage. In this stage temperature of the compressed air is lowered using a cooler and the air is dried using a dryer.

-> Also an inline filter is provided to remove any contaminant particles present. This treatment is called primary air treatment.

-> In the 3rd stage which is the secondary air treatment process, further filtering is carried out.

FILTERS

-> To prevent any damage to the compressor, the contaminants present in the air need to be filtered out. This is done by using inlet filters.

-> This can be dry / wet filters.

-> Dry filters use disposable catridges.

-> In the wet filter, the incoming air is passed through an oil bath & then through a fine wire mesh filter.

-> Dirt particles cling to the oil drops during bubbling & are removed by wire mesh as they pass through it.

-> In the dry filter the catridges are replaced during servicing. The wet filters are cleaned using detergent solution.

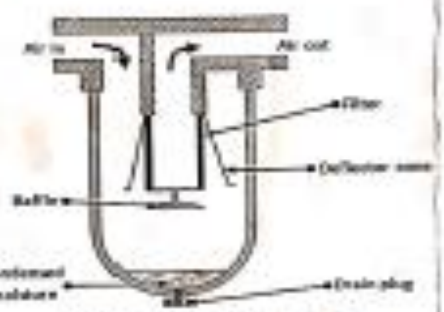
AIR DRIERS:

-> These are used to remove the water vapours or solid contaminants present in the pneumatic systems main lines

Air filter & Water trap :

→ Air filter and water trap is used to

- prevent any solid contaminants from entering in the System
- Condense and remove water vapour that is present in the Compressed air .



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→ The filter cartridge is made of Sintered brass .

→ The thickness of sintered Catridge provides random zig zag passage for the air to flow in which helps in arresting solid particles .

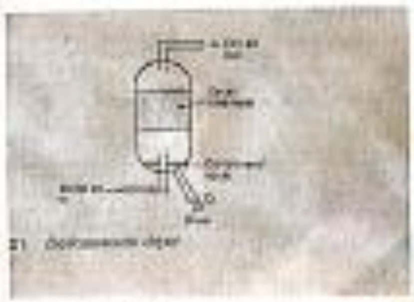
→ The air entering the filter swirls around due to the deflection cone

→ The centrifugal action causes the large contaminants and water vapour to be flung out , which hit the glass bowl and get Collected at the bottom .

→ A baffle plate is provided to prevent the turbulent air from Splashing the water into the filter cartridge

→ At the bottom of the filter bowl there is a drain plug which can be opened manually to drain off the settled water and solid particles.

DELIQUESCENT DRIERS



-> In the deliquescent dryer, a chemical agent called a desiccant is used.

-> This absorbs water vapour and slowly dissolves to form a liquid which collects at the bottom of the unit where it can be drained.

-> The desiccant material is used up during this process and needs to be replaced at regular intervals.

-> often deliquesant dryers are refered to as absorption dryers.

Lubricators

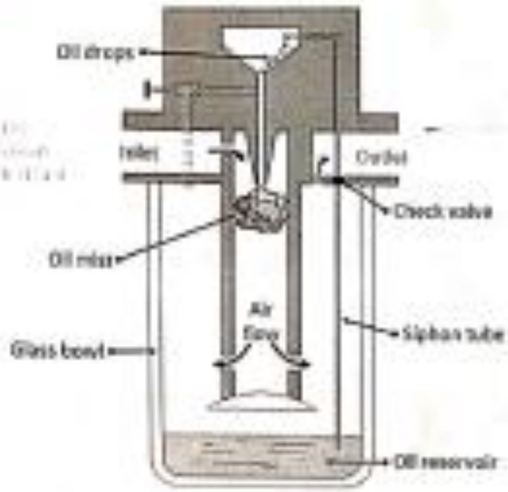


Fig. 6.3.6 Air lubricator

The compressed air is first filtered and then passed through a lubricator in order to form a mist of oil and air to provide lubrication to the mating components. Figure 6.3.6 shows the schematic of a typical lubricator. The principle of working of venturimeter is followed in the operation of lubricator. The compressed air from the dryer enters in the lubricator. Its velocity increases due to a pressure differential between the upper and lower changer (oil reservoir). Due to the low pressure in the upper chamber the oil is pushed into the upper chamber from the oil reservoir through a siphon tube with check valve. The main function of the valve is to control the amount of oil passing through it. The oil drops inside the throttled zone where the velocity of air is much higher and this high velocity air breaks the oil drops into tiny particles. Thus a mist of air and oil is generated. The pressure differential across chambers is adjusted by a needle valve. It is difficult to hold an oil mixed air in the air receiver as oil may settle down. Thus air is lubricated during secondary air treatment process. Low viscosity oil forms better mist than high viscosity oil and hence ensures that oil is always present in the air.

Chemical dryers

When absolute dry air is needed chemical dryers are used. These dryers are of two types viz. adsorption dryer and absorption dryer.

Adsorption dryers

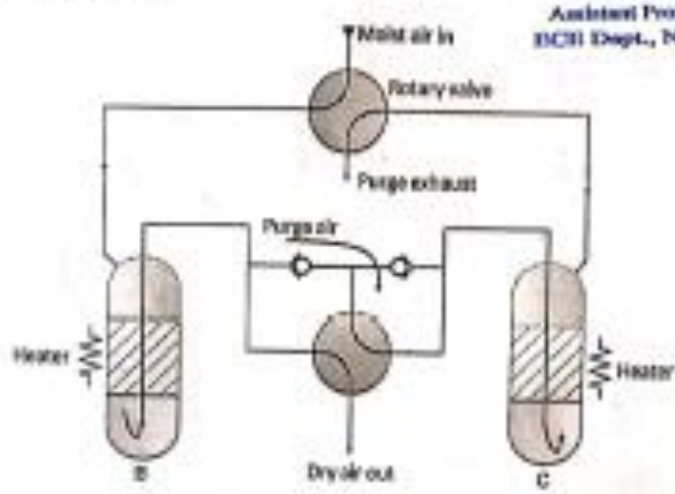


Fig. 6.3.4 Adsorption dryer

In Adsorption dryers, the moisture collects on the sharp edges of the granular material. The adsorbing materials can be silicon dioxide (silica gel) or other materials which exist in hydrated and dehydrated state (copper sulphate, activated alumina). Moisture from the adsorbing material can be released by heating in the column as shown in Fig. 6.3.4. At a given time, one column will dry the air while the other column will regenerate the adsorption material by heating and passing low purge air. The column B dries the air and column C regenerates. The rotary valves are opened using time clock at regular interval to reverse the process. These dryers are also called regenerative dryers.

Types of Pressure Regulation

(10)

Pressure regulation

In pneumatic systems, during high velocity compressed air flow, there is flow-dependent pressure drop between the receiver and load (application). Therefore the pressure in the receiver is always kept higher than the system pressure. At the application site, the pressure is regulated to keep it constant. There are three ways to control the local pressure, these are shown in Figure 6.3.7.

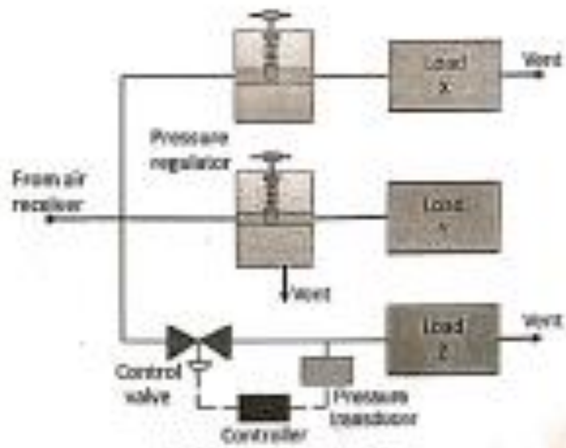


Fig. 6.3.7 Types of pressure regulation

- In the first method, load X vents the air into atmosphere continuously. The pressure regulator restricts the air flow to the load, thus controlling the air pressure. In this type of pressure regulation, some minimum flow is required to operate the regulator. If the load is a dead end type which draws no air, the pressure in the receiver will rise to the manifold pressure. These type of regulators are called as 'non-relieving regulators', since the air must pass through the load.
- In the second type, load Y is a dead end load. However the regulator vents the air into atmosphere to reduce the pressure. This type of regulator is called as 'relieving regulator'.
- The third type of regulator has a very large load Z. Therefore its requirement of air volume is very high and can't be fulfilled by using a simple regulator. In such cases, a control loop comprising of pressure transducer, controller and vent valve is used. Due to large load the system pressure may rise above its critical value. It is detected by a transducer. Then the signal will be processed by the controller which will direct the valve to be opened to vent out the air. This technique can be also be used when it is difficult to mount the pressure regulating valve close to the point where pressure regulation is needed.

Relief valve

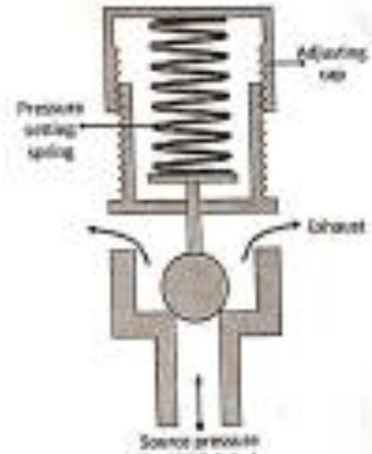


Fig. 6.3.8 Relief valve

Relief valve is the simplest type of pressure regulating device. The schematic of its construction and working is shown in the Figure 6.3.8. It is used as a backup device if the main pressure control fails. It consists of ball type valve held on to the valve seat by a spring in tension. The spring tension can be adjusted by using the adjusting cap. When the air pressure exceeds the spring tension pressure the ball is displaced from its seat, thus releasing the air and reducing the pressure. A relief is specified by its span of pressure between the cracking and full flow, pressure range and flow rate. Once the valve opens (cracking pressure), flow rate depends on the excess pressure. Once the pressure falls below the cracking pressure, the valve seals itself.

11

Non-relieving pressure regulator

In a non-relieving pressure regulator (Fig. 6.3.9) the outlet pressure is sensed by a diaphragm which is preloaded by a pressure setting spring. If outlet pressure is too low, the spring forces the diaphragm and poppet to move down thus opening the valve to admit more air and raise outlet pressure. If the outlet pressure is too high the air pressure forces the diaphragm up hence reduces the air flow and causing a reduction in air pressure. The air vents away through the load. At steady state condition the valve will balance the force on the diaphragm from the outlet pressure with the preset force on the spring.

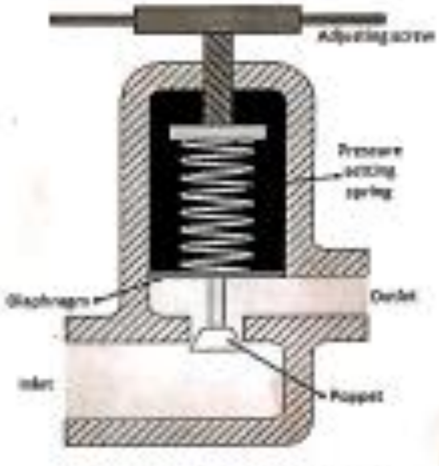


Fig. 6.3.9 Non-relieving type pressure regulator

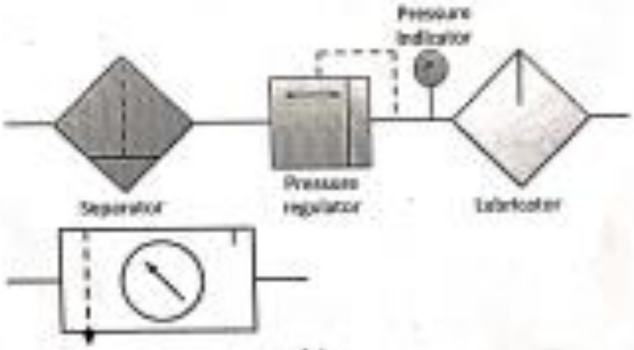
Relieving pressure regulator

Refer pg NO: 80, 81, 82

Service units

During the preparation of compressed air, various processes such as filtration, regulation and lubrication are carried out by individual components. The individual components are: separator/filter, pressure regulator and lubricator.

Preparatory functions can be combined into one unit which is called as 'service unit'. Figure 6.3.10 shows symbolic representation of various processes involved in air preparation and the service unit.



(a) (b)

Fig. 6.3.10 (a) Service unit components (b) Service unit symbol

MODULE 3

CONTROL VALVES

A **control valve** is a valve used to control fluid flow by varying the size of the flow passage as directed by a signal from a controller. This enables the direct control of flow rate and the consequential control of process quantities such as pressure, temperature, and liquid level. The opening or closing of automatic control valves is usually done by electrical, hydraulic or pneumatic actuators. Normally with a modulating valve, which can be set to any position between fully open and fully closed, valve positioners are used to ensure the valve attains the desired degree of opening.

Air-actuated valves are commonly used because of their simplicity, as they only require a compressed air supply, whereas electrically-operated valves require additional cabling and switch gear, and hydraulically-actuated valves required high pressure supply and return lines for the hydraulic fluid.

The pneumatic control signals are traditionally based on a pressure range of 3-15psi (0.2-1.0 bar), or more commonly now, an electrical signal of 4-20mA for industry, or 0-10V for HVAC systems. Electrical control now often includes a "Smart" communication signal superimposed on the 4-20mA control current, such that the health and verification of the valve position can be signaled back to the controller. The HART, Fieldbus Foundation, and Profibus are the most common protocols.

GRAPHIC SYMBOLS

Pneumatic and hydraulic systems require control valves to direct and regulate the flow of fluid from compressor or pump to the various load devices. Although there are significant practical differences between pneumatic and hydraulic devices (mainly arising from differences in operating pressures and types of seals needed for gas or liquid) the operating principles and descriptions are very similar. Although valves are used for many purposes, there are essentially only two types of valve. An infinite position valve can take up any position between open and closed and, consequently, can be used to modulate flow or pressure. Relief valves described in earlier chapters are simple infinite position valves.

Most control valves, however, are only used to allow or block flow of fluid. Such valves are called finite position valves. An analogy between the two types of valve is the comparison between an electric light dimmer and a simple on/ off switch. Connections to a valve are termed ‘ports’. A simple on/off valve therefore has two ports. Most control valves, however, have four ports, shown in hydraulic and pneumatic forms in Figure 4.1. In both the load is connected to ports labeled A, B and the pressure supply (from pump or compressor) to port P. In the hydraulic valve, fluid is returned to the tank from port T. In the pneumatic valve return air is vented from port R. Figure 4.2 shows internal operation of valves. To extend the ram, ports P and B are

connected to deliver fluid and ports A and T connected to return fluid. To retract the ram, ports P and A are connected to deliver fluid and ports B and T to return fluid.
Another consideration is the number of control positions. Figure 4.3 shows two possible control schemes. In Figure 4.3a, the ram is controlled by a lever with two positions: extend or retract. This valve has two control positions (and the ram simply drives to one end or the other of its stroke). The valve in Figure 4.3b has three positions: extend, off, retract. Not surprisingly the valve in Figure 4.3a is called a two-position valve, while that in Figure 4.3b is a three-position valve.
Finite position valves are commonly described as a port/position valve where port is the number of ports and position is the number of positions. Figure 4.3a therefore illustrates a 4/2 valve, and Figure 4.3b shows a 4/3 valve. A simple block/allow valve is a 2/2 valve. The numbers of ports and positions do not, however, completely describe the valve. We must also describe its action. Figure 4.4 shows one possible action for the 4/3 valve of Figure 4.3b. Extend and retract connections are similar, but in the off position ports P and T are connected – unloading the pump back to the 75 Hydraulics and Pneumatics.

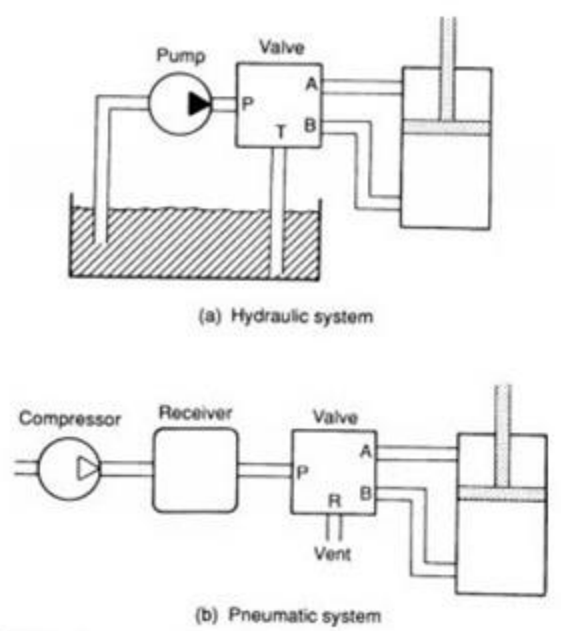


FIGURE 4.1 Valves in a pneumatic and a hydraulic system

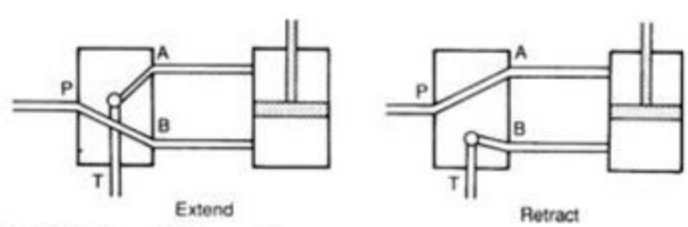


FIGURE 4.2 Internal valve operation

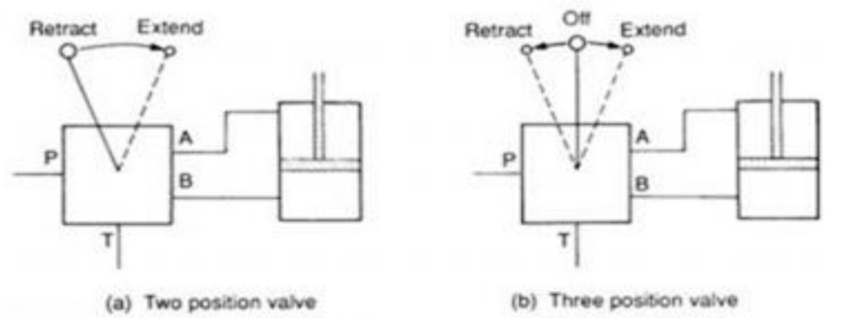


FIGURE 4.3 Valve control positions

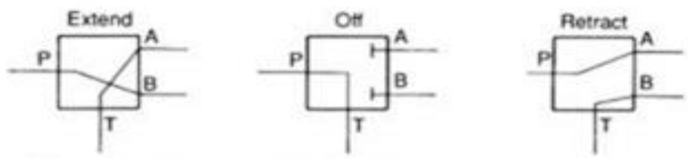
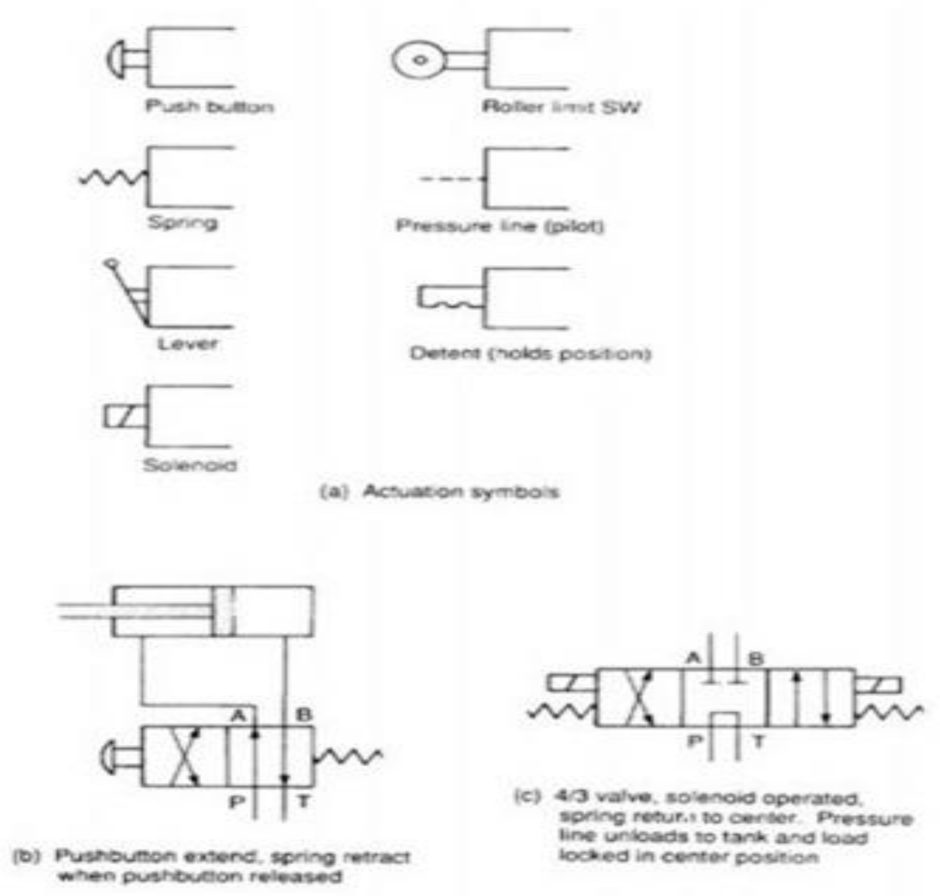


FIGURE 4.4 Possible valve action for a 4/3 valve



TYPES OF CONTROL VALVES

BASIC VALVE TYPES Valves are available with a wide variety of valve bodies in various styles, materials, connections and sizes. Selection is primarily dependent on the service conditions, the task, and the load characteristics of the application. The most common types are ball valves, butterfly valves, globe valves, and gate valves. Ball Valves: Ball valves are quick opening valves that give a tight shutoff. When fully open, a ball valve creates little turbulence or resistance to flow. The valve stem rotates a ball which contains an opening. The ball opening can be positioned in the fully open or fully closed position but must not be used to throttle flow as any abrasive wear to the ball will cause leakage when the valve is closed. Ball valves are considered high recovery valves, having a low pressure drop and relatively high flow capacity.

Best Suited Control: Quick opening, linear

- Recommended Uses: • Fully open/closed,
- Limited-throttling • Higher temperature fluids Applications:
- Ball valves are excellent in chemical applications, including the most challenging services (e.g. dry chlorine, hydrofluoric acid, oxygen).
  General sizes available are 1/2" to 12".

• Compliant with ASME is the flange rating, either 150, 300, 600, 900# or occasionally higher classes, enabling high performance ball valves to withstand up to 2250 psi.

• The operating temperature which is primarily dependent on seats and seals may be rated as high as 550°F.

• Standard valves comply with ASME face-to-face dimensions, making the ball valve easy to retrofit and replace. Advantages:

• Low cost • High flow capacity

• High pressure/temperature capabilities

• Low leakage and maintenance

• Tight sealing with low torque

• Easy quarter turn operation- desirable to most operators

• Fairly easy to automate. Disadvantages:

• Limited throttling characteristics

• Prone to cavitation

• Not suitable for slurry applications due to cavities around the ball and seats.

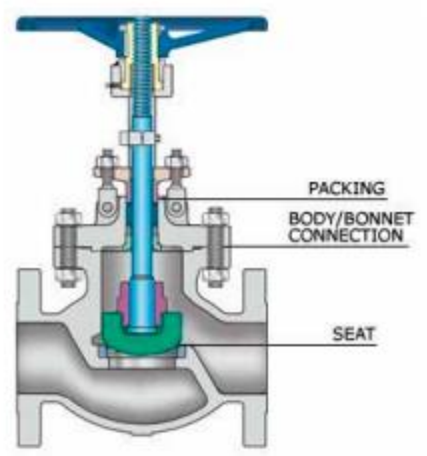
Slurries tend to solidify or clog inside the cavities, greatly increasing the operating torque of the valve and in some cases rendering the valve inoperable. Butterfly Valves: Butterfly valves consist of a disc attached to a shaft with bearings used to facilitate rotation. These are considered high recovery valves, since only the disc obstructs the valve flow path. The flow capacity is relatively high and the pressure drop across the valve is relatively low. The butterfly valves are used for limited throttling where a tight shut off is not required. When fully open, the butterfly creates little turbulence or resistance to flow.

Butterfly Valves:

- Butterfly valves consist of a disc attached to a shaft with bearings used to facilitate rotation. These are considered high recovery valves, since only the disc obstructs the valve flow path.
- The flow capacity is relatively high and the pressure drop across the valve is relatively low. The butterfly valves are used for limited throttling where a tight shut off is not required. When fully open, the butterfly creates little turbulence or resistance to flow.

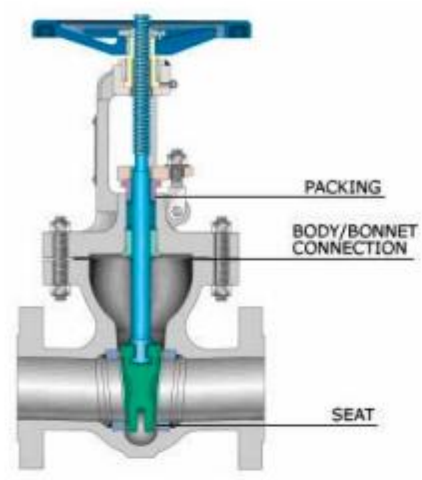
Globe Valves:

Globe valves consist of a movable disk-type element and a stationary ring seat in a generally spherical body. The valve stem moves a globe plug relative to the valve seat. The globe plug can be at any position between fully opened and fully closed to control flow through the valve. The globe and seat construction gives the valve good flow regulation characteristics. Turbulent flow past the seat and plug, when the valve is open, results in a relatively high pressure drop, limited flow capacity, and low recovery.

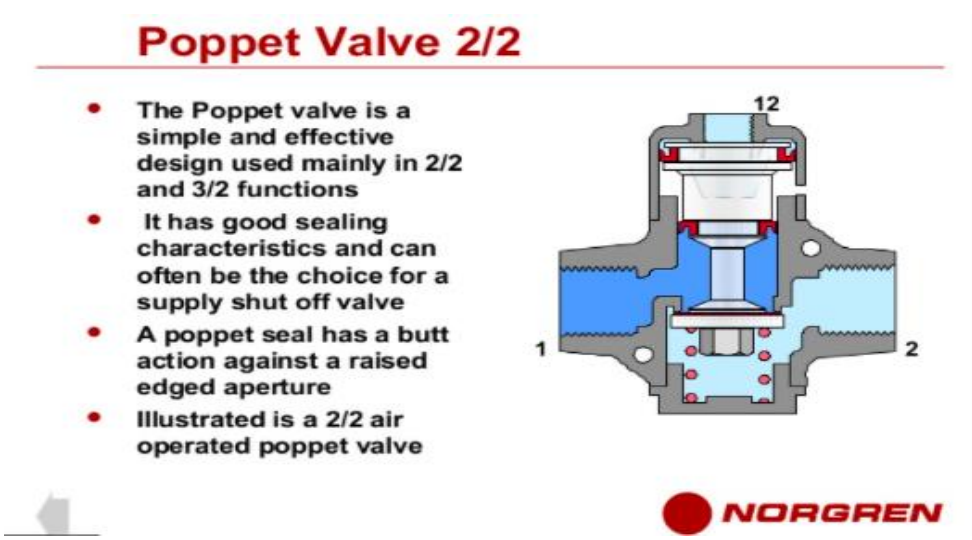


Gate Valves:

Gate valves use linear type of stem motion for opening and closing of a valve. These valves use parallel or wedge shaped discs as closure members that provide tight sealing.

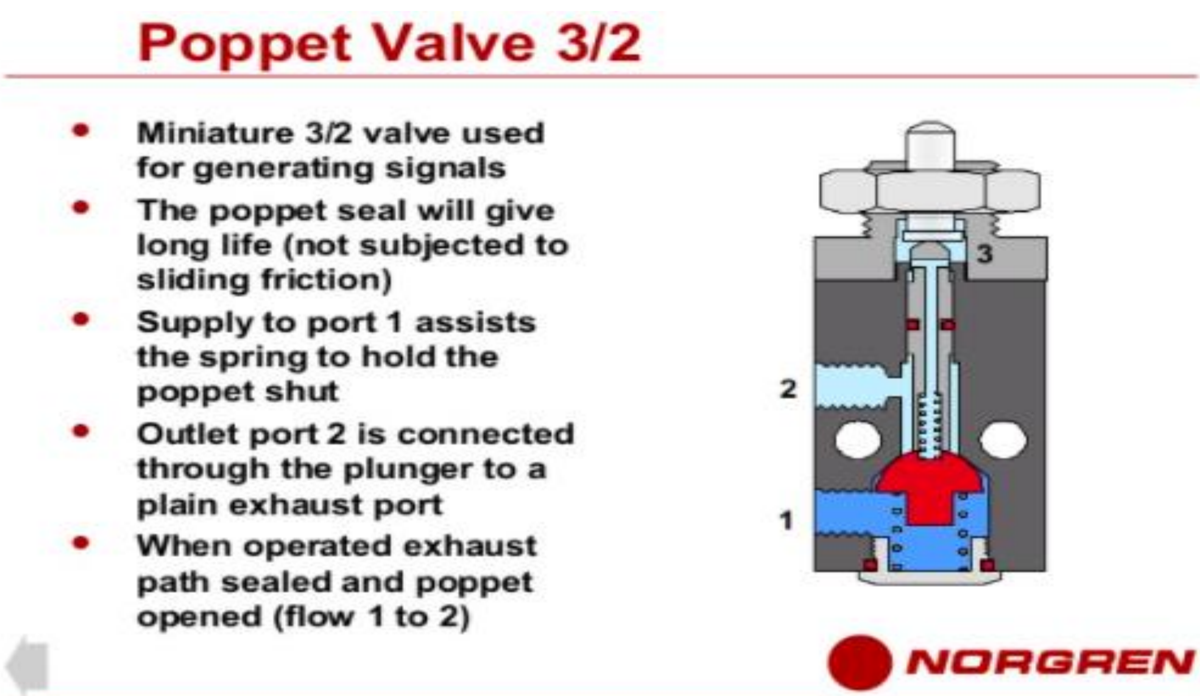


SIMPLE 2/2 POPPET VALVE

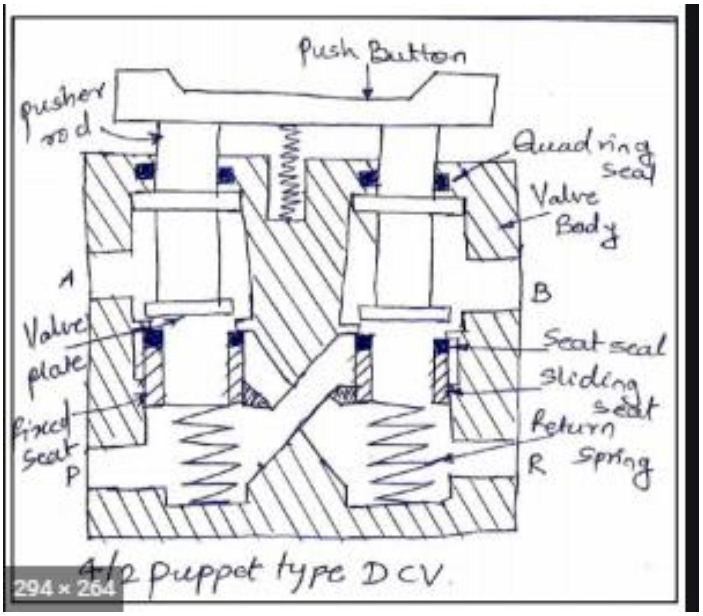
- A **poppet valve** (also called **mushroom valve** is a valve typically used to control the timing and quantity of gas or vapor flow into an engine.
- It consists of a hole or open-ended chamber, usually round or oval in cross-section, and a plug, usually a disk shape on the end of a shaft known as a valve stem. The working end of this plug, the valve face, is typically ground at a 45° bevel to seal against a corresponding valve seat ground into the rim of the chamber being sealed. The shaft travels through a valve guide to maintain its alignment.
- A pressure differential on either side of the valve can assist or impair its performance. In **exhaust** applications higher pressure against the valve helps to seal it, and in **intake** applications lower pressure helps open it.
- 

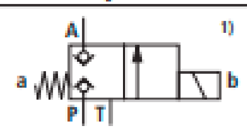
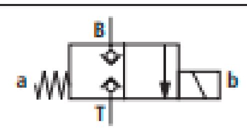
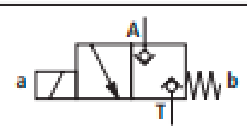
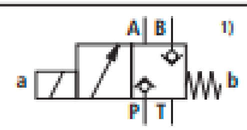
Poppet valve & components

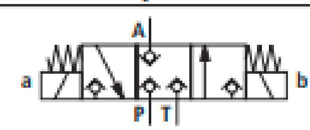
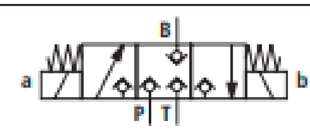
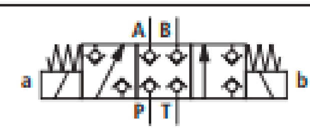
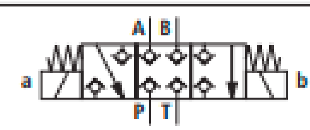
3/2POPPET VALVE



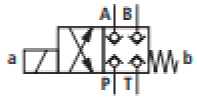
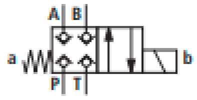
4/2 POPPET VALVE

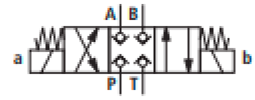
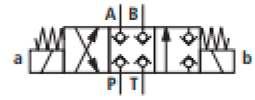
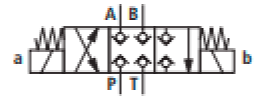
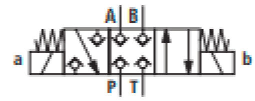
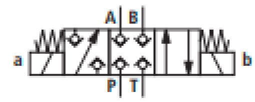


2/2 directional poppet valve	
Ordering code	**Symbol**
E61B	
E40B	
E69A	
E18A	

3/3 directional poppet valve	
Ordering code	**Symbol**
E35	
E100	
E13	
E22 [2]	

[1] Port T must be connected for pressure compensation.
[2] Port P doesn't have to be be connected.

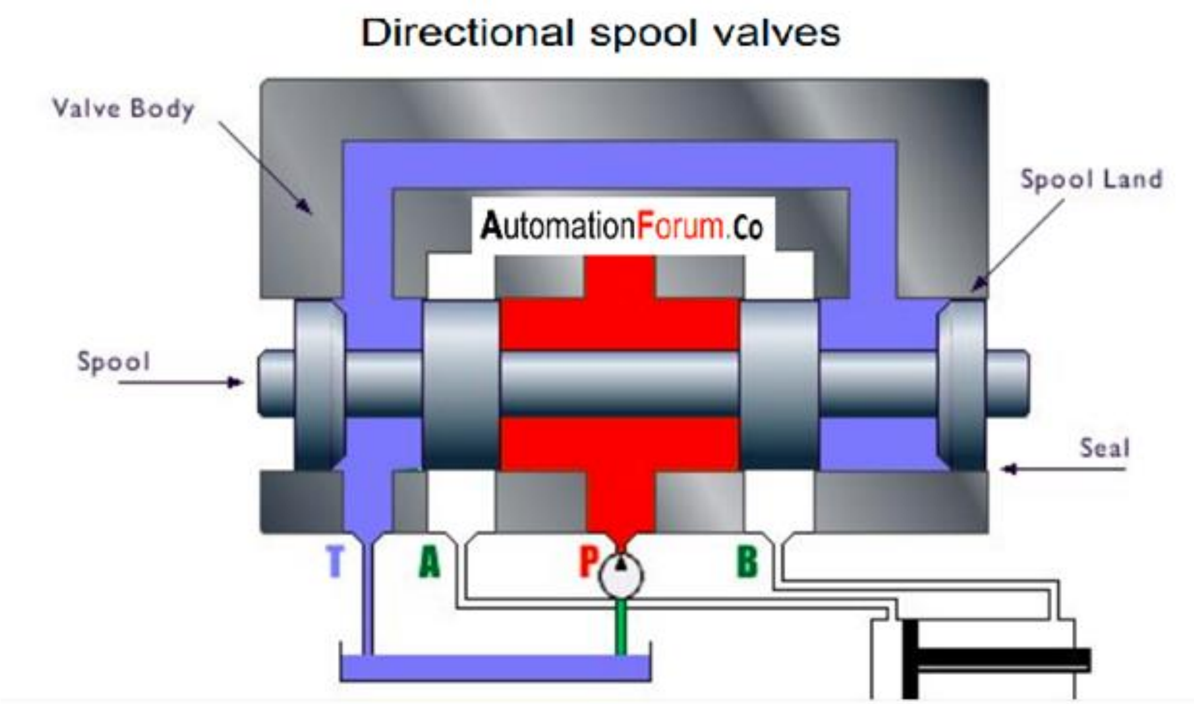
4/2 directional poppet valve	
Ordering code	Symbol
EA	
EB	

4/3 directional poppet valve	
Ordering code	Symbol
E	
E61	
E40	
E89	
E18	

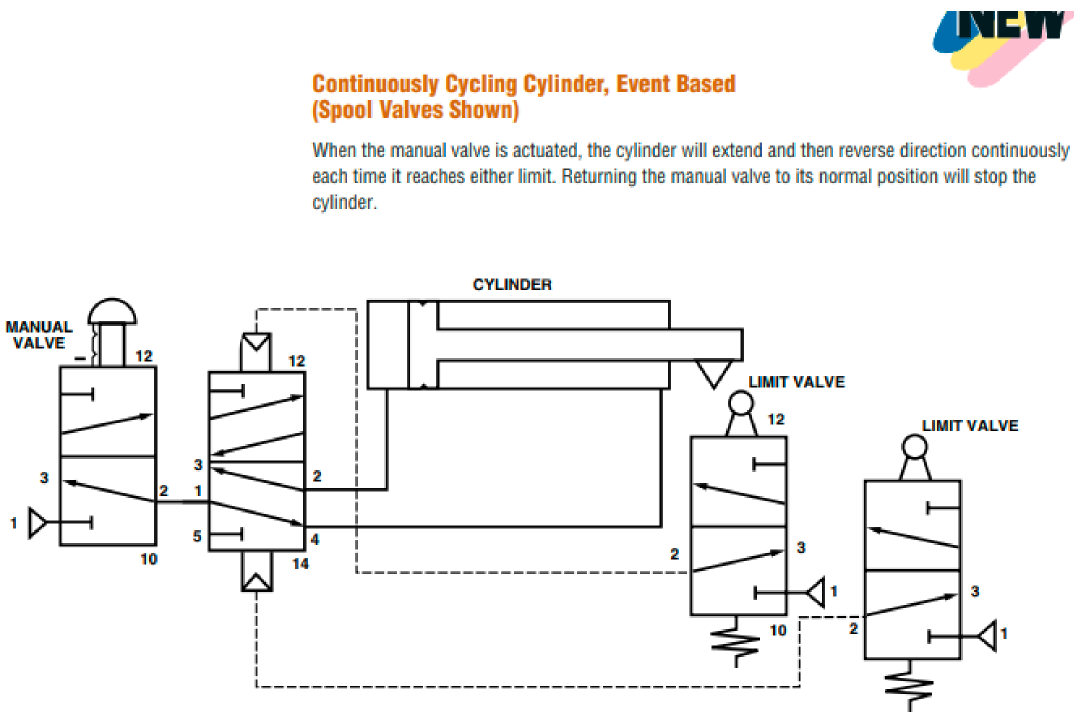
SPOOL VALVES

Spool valves are normally designed so that the leakage in the spool is small compared to the hydraulic system flow rate. Spool can be considered as a valve component that has seals mounted along its surface. When the valve is actuated, the spool shifts cause the seals to travel along the bore, opening ports to allow airflow. Spool valves regulate the flow of fluid in hydraulic systems. Spool valves would slide backward and forward so that the fluid flow can be either in one direction or another around a circuit of pipes.

Spool valves have two basic components, a cylindrical barrel in which slides a plunger or spool. Blocking of the ports is done by glands, it can also be done by the spools diameter section, with the intervening waists sections that also does the interconnection of the port through the barrel. So that it is can do multi-way and multi-positioning switching. Spool valves are very simple and are low of cost, to get a proper sealing a proper surface finish is needed for the barrel bore and spool and requires close tolerance to provide practical minimum clearance. Glandless spool valves mostly need a lapped fit between spool and body.



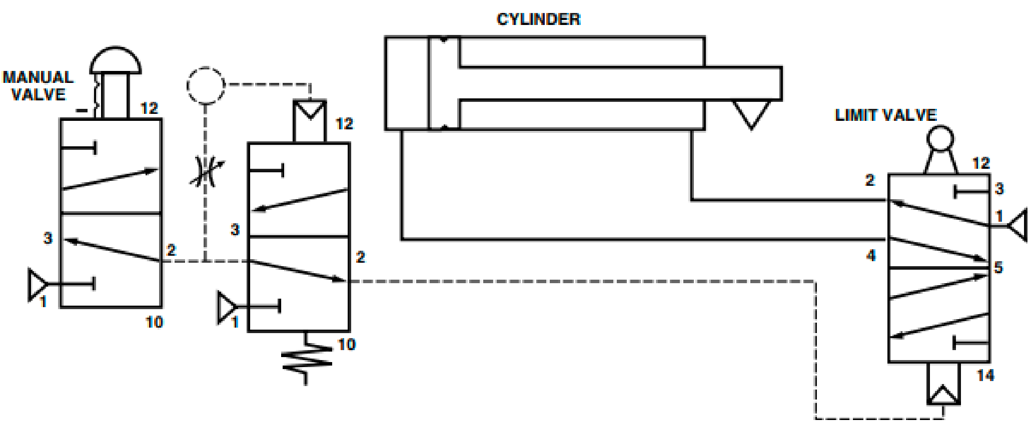
TWO WAY AND FOUR WAY SPOOL VALVES



THREE POSITION FOUR WAY VALVE

One Cycle Cylinder Operation with a Short or Long Manual Start Signal (Spool Valves Shown)

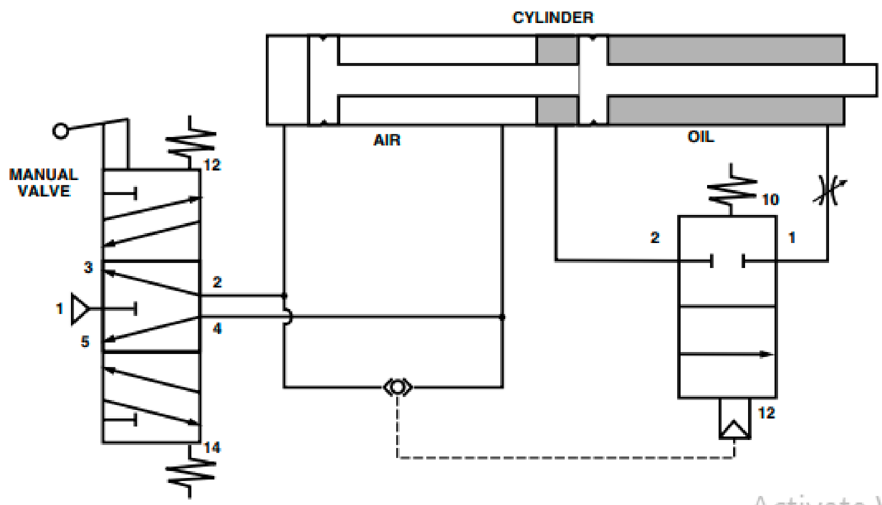
This circuit will cause the cylinder to cycle once, regardless of how long the manual start signal is applied. The manual valve has to be released before another cycle can be started.



PILOT OPERATED 3/2 VALVE

Cylinder Feed Rate Control with Positive Lock in any Cylinder Position (Spool Valves Shown) (Air Over Oil Cylinder)

This circuit provides a constant cylinder feed rate for both directions of travel. In addition, the cylinder will lock in position when the manual valve is centered. Air provides the force to move the cylinder; oil, with its feature of non-compressibility, is used to give smooth cylinder motion.



Z-219

ROTARY VALVE

A **rotary valve** is a type of valve in which the rotation of a passage or passages in a transverse plug regulates the flow of liquid or gas through the attached pipes. The common stopcock is the simplest form of rotary valve. Rotary valves have been applied in numerous applications, including:

- Changing the pitch of brass instruments.
- Controlling the steam and exhaust ports of steam engines, most notably in the Corliss steam engine.
- Periodically reversing the flow of air and fuel across the open hearth furnace.
- Loading sample on chromatography columns.
- Certain types of two-stroke and four-stroke engines.
- Most hydraulic automotive power steering control valves
  - In the context of brass instruments, rotary valves are found on horns, trumpets, trombones, flugelhorns, and tubas. Many European trumpet players tend to favor rotary valves
  - Trombone F-attachment valves are usually rotary, with several variations on the basic design also in use, such as the Thayer axial-flow valve and Hagmann valve.
  - Joseph Riedl is credited with the first use of rotary valves on brass instruments in 1832

Rotary valves on a trumpet

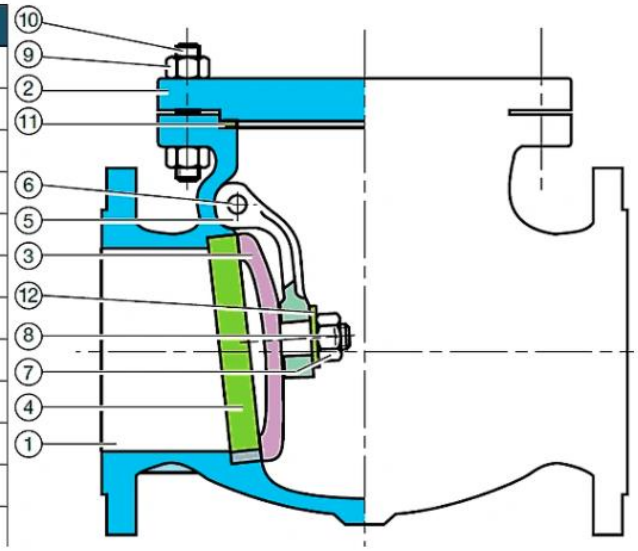
CHECK VALVE

The valve that used to prevent backflow in a piping system is known as a check valve. It is also known as a non-return valve or NRV. The pressure of the fluid passing through a pipeline opens the valve, while any reversal of flow will close the valve.

It allows full unobstructed flow and automatically shuts as pressure decreases. The exact operation will vary depending on the mechanism of the valve.

It is consists of body, cover, disk, hinge pin, and seat ring. In the image below you can see the parts of the valve.

Sr No	Check Valve
1	Body
2	Cover plate
3	Disc
4	Body seats
5	Hinge
6	Hinge pin
7	Nut
8	Cotter pin
9	nuts
10	Stud bolts
11	gasket
12	Washer

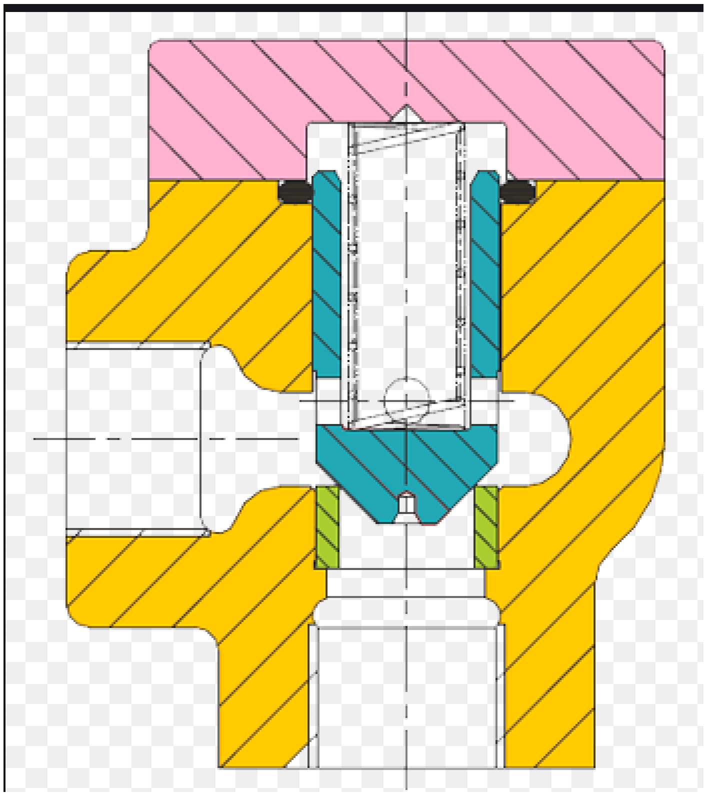


SIMPLE CHECK VALVE

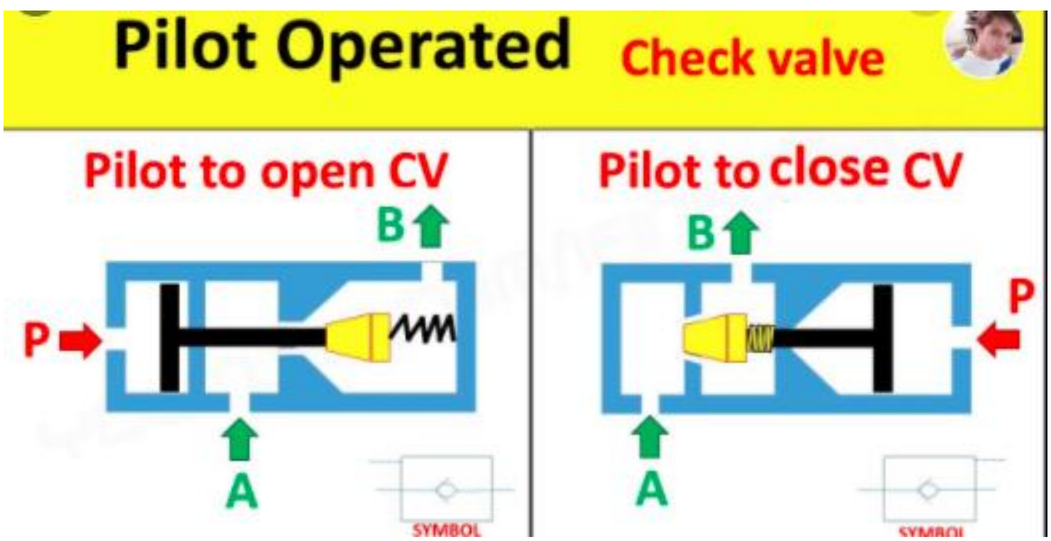
Check valves are often essential components in microfluidic devices, enabling automated sample processing for diagnostics at the point of care. However, there is an unmet need for a check valve design that is compatible with rigid thermoplastic devices during all stages of development—from initial prototyping with a laser cutter to final production with injection molding. Here, we present simple designs for a passive, normally closed check valve that is manufactured from commonly available materials with a CO_2 laser and readily integrated into prototype and production thermoplastic devices. The check valve consists of a thermoplastic planar spring and a soft elastomeric pad that act together to seal against fluid backflow. The valve's cracking pressure can be tuned by modifying the spring's planar geometry and thickness. Seal integrity is improved with the addition of a raised annular boss beneath the elastomeric pad. To demonstrate the valve's usefulness, we employ these valves to create a finger-operated on-chip reagent reservoir and a finger-actuated pneumatic pump. We also apply this check valve to passively seal a device to enable portable detection of RNA from West Nile virus in a laser-cut device.

RIGHT ANGLE CHECK VALVE

These **valves** allow free flow in one direction and prevent flow in the reverse direction. Cracking pressure specified. is the pressure required to open the **valve** and allow free flow.



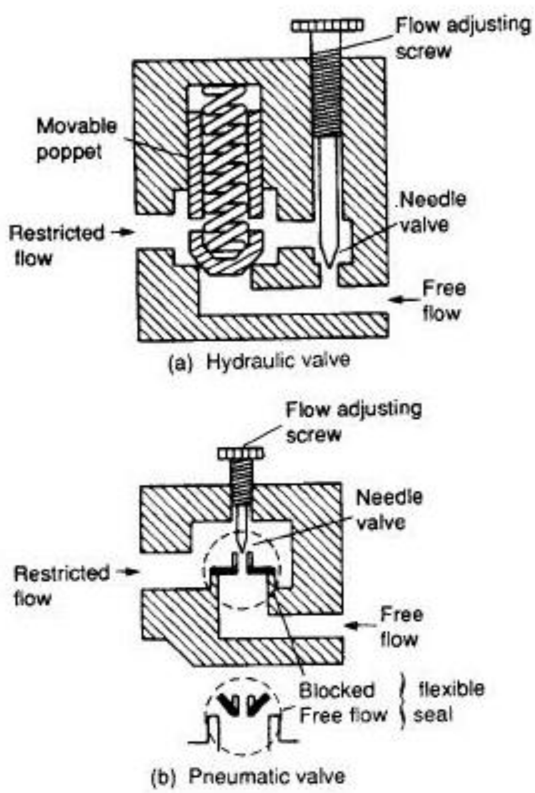
PILOT OPERATED CHECK VALVE



In the PORV, the **valve** is held shut by piping a small amount of the fluid to the rear of the sealing disk, with the pressure balanced on either side. A separate actuator on the piping releases pressure in the line if it crosses a threshold. This releases the pressure on the back of the seal, causing the **valve** to open.

RESTRICTION CHECK VALVE

The speed of a hydraulic or pneumatic actuator can be controlled by adjusting the rate at which a fluid is admitted to, or allowed out from, a device. A restriction check valve (often called a throttle relief valve in pneumatics) allows full flow in one direction and a reduced flow in the other direction. Figure 4.24a shows a simple hydraulic valve and Figure 4.24b a pneumatic valve. In both, a needle valve sets restricted flow to the required valve. The symbol of a restriction check valve is shown in Figure 4.24c. Figure 4.24d shows a typical application in which the cylinder extends at full speed until a limit switch makes, then extend further at low speed. Retraction is at full speed. A restriction check valve V 2 is fitted in one leg of the cylinder. With the cylinder retracted, limit-operated valve V 3 is open allowing free flow of fluid from the cylinder as it extends. When the striker plate on the cylinder ram hits the limit, valve V 3 closes and flow out of the cylinder is now restricted by the needle valve setting of valve V 2. In the reverse direction, the check valve on valve V 2 opens giving full speed of retraction.

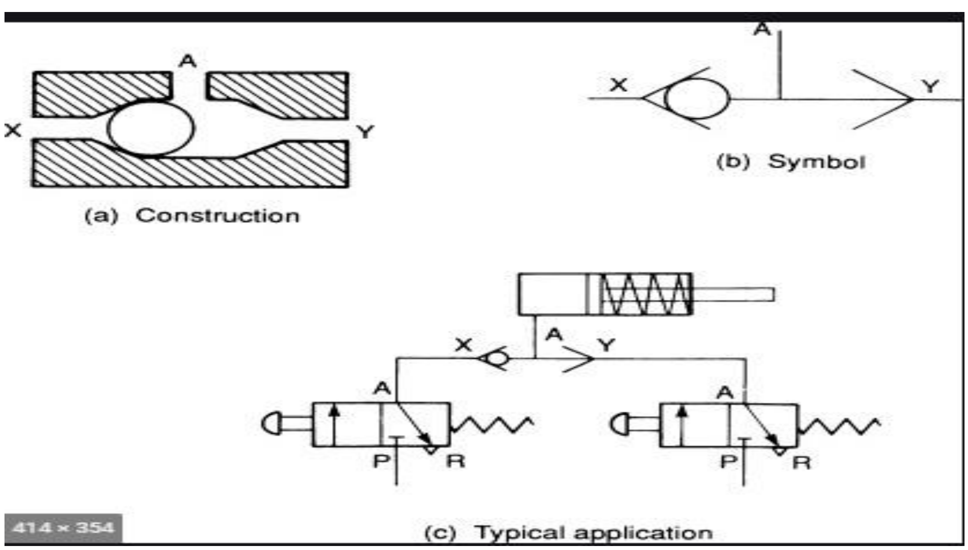


SHUTTLE VALVE

The basic structure of a shuttle valve is like a tube with three openings; one on each end, and one in the middle. A ball or other blocking valve element moves freely within the tube.
When pressure from a fluid is exerted through an opening on one end it pushes the ball towards the opposite end. This prevents the fluid from traveling through that opening, but allows it to flow through the middle opening. In this way two different sources can provide pressure without the threat of back flow from one source to the other. In pneumatic logic a shuttle-valve works as an OR gate

A shuttle valve has several applications including:

1. The use of more switches on one machine: by using the shuttle valve, more than one switch can be operated on a single machine for safety, and each switch can be placed at any suitable location. This application is normally used with heavy industrial machinery.
2. Winch brake circuit: a shuttle valve provides brake control in pneumatic winch applications. When the compressor is operated the shuttle valves direct air to open the brake shoes. When the control valve is centered, the brake cylinder is vented through the shuttle valve, and the brake shoes are allowed to close.
3. Air pilot control: converting from air to oil results in locking of the cylinder. Shifting the four-way valve to either extreme position applies the air pilot through the shuttle valve, holding the two air-operated valves open and applying oil under air pressure to the corresponding side of the cylinder. Positioning a manual valve to neutral exhausts the air pilot pressure, closing the two-way valves, and trapping oil on both sides of the cylinder to lock it in position.
4. Standby and emergency systems: compressor systems requiring standby or purge gases capability are pressure controlled by the shuttle valve. This is used for instrumentation, pressure cables, or any system requiring continuous pneumatic input. If the compressor fails, the standby tank—regulated to slightly under the compressor supply—will shift the shuttle valve and take over the function. When the compressor pressure is re-established, the shuttle valve shifts back and seals off the standby system until needed again.

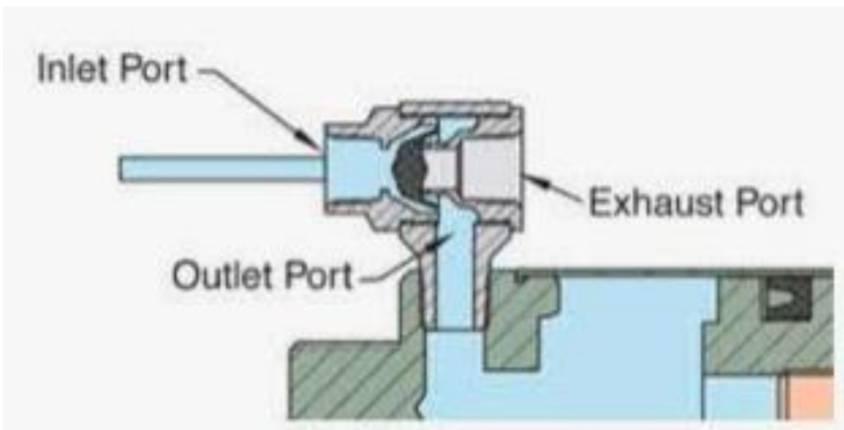


FAST EXHAUST VALVES

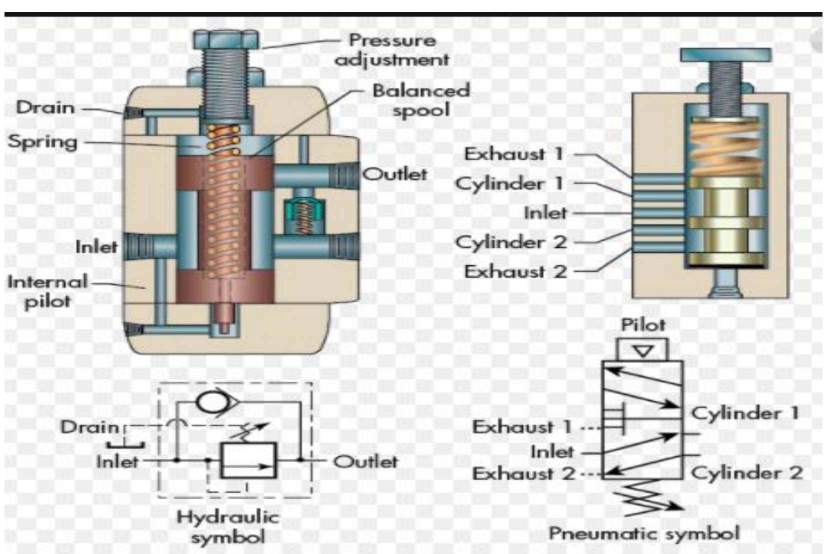
Quick exhaust valves are exceptionally handy fittings that can be used in many different sectors of the industry to increase the cycle speed of a pneumatic cylinder. They do this by allowing the air that is coming out of the pneumatic cylinder to be directed into the atmosphere instead of flowing back through the valve and slowing the process down. In this article, MGA Controls will be discussing how a quick exhaust valve works and pneumatic quick exhaust valve applications.

Quick exhaust valves are installed at the rod or blind end of a pneumatic cylinder to provide a quick extension and retraction of the equipment. Quick exhaust valves operate by increasing the speed of the pneumatic cylinder's rod in order to expel the exhaust air at the port of the cylinder directly.

One quick exhaust valve is used in each port of the cylinder to ensure an increase in the speed of the rod in both directions. The use of a quick exhaust valve in a pneumatic system helps to increase cycling speed, in turn, that ensures a much smaller valve to be effectively used for the process.

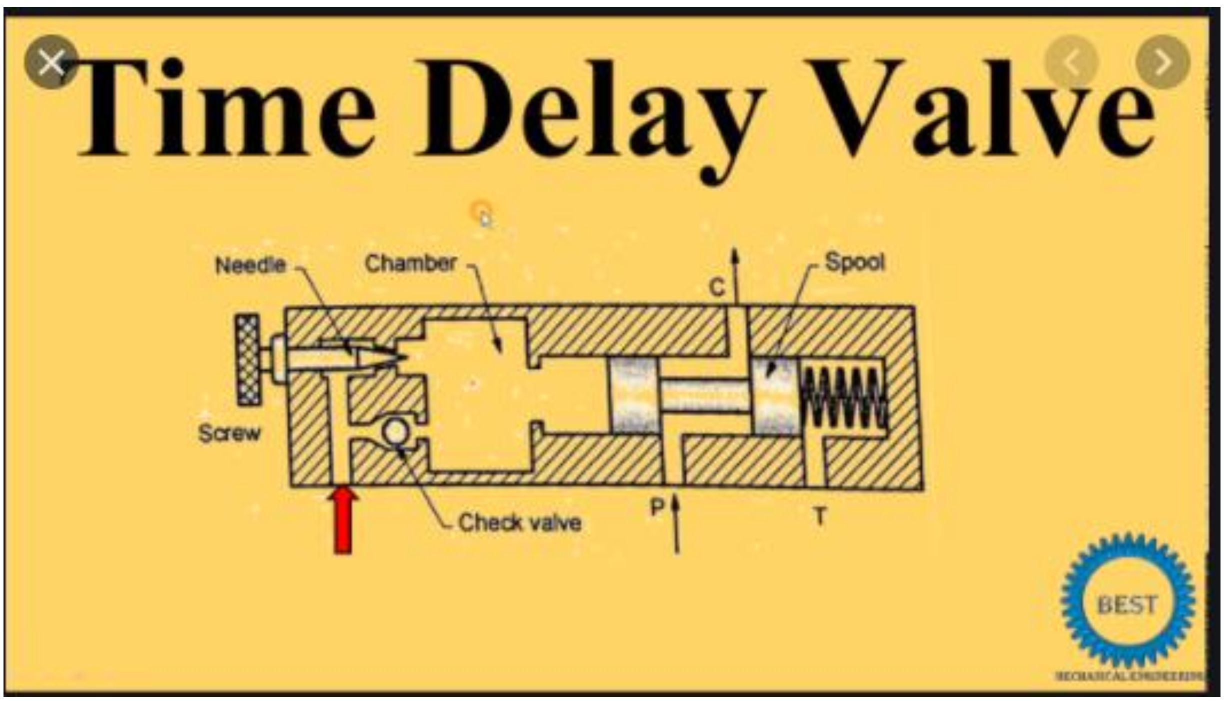


SEQUENCE VALVE



There are times when two or more cylinders need to stroke in a planned sequence. With two or more cylinders controlled by a single directional valve, the cylinder with the lowest resistance always strokes first. If the actuator with the least resistance is first in the sequence, the circuit runs smoothly without other valving. When the cylinder that must move first has the highest resistance, a single directional control will not work. A separate directional valve for each cylinder is one way to sequence such a circuit. Energizing one solenoid extends the first cylinder. When the first cylinder contacts a limit switch, it energizes a second solenoid, causing the next cylinder to stroke. With this type of sequencing circuit, the first cylinder may lose holding power when the second directional valve shifts. It may require other valves to make sure the first cylinder generates and maintains the force required both before and during the second cylinder's stroke. Another way to force fluid to take the path of greatest resistance is to use a pressure-control valve called a sequence valve.

TIME DELAY VALVE



Time delay valve is a combination valve used to set the operation time as per the requirement. The time delay can be increased or decreased by adjusting the flow through the non-return flow control valve. The change invariably increases or decreases the time taken to fill and pilot actuates the direction control valve. Time delay valve is a combination of a pneumatically actuated 3/2 direction control valve, an air reservoir and a throttle relief valve. The time delay function is obtained by controlling the air flow rate to or from the reservoir by using the throttle valve. Adjustment of throttle valve permits fine control of time delay between minimum and maximum times. In pneumatic time delay valves, typical time delays in the range 5-30 seconds are possible.

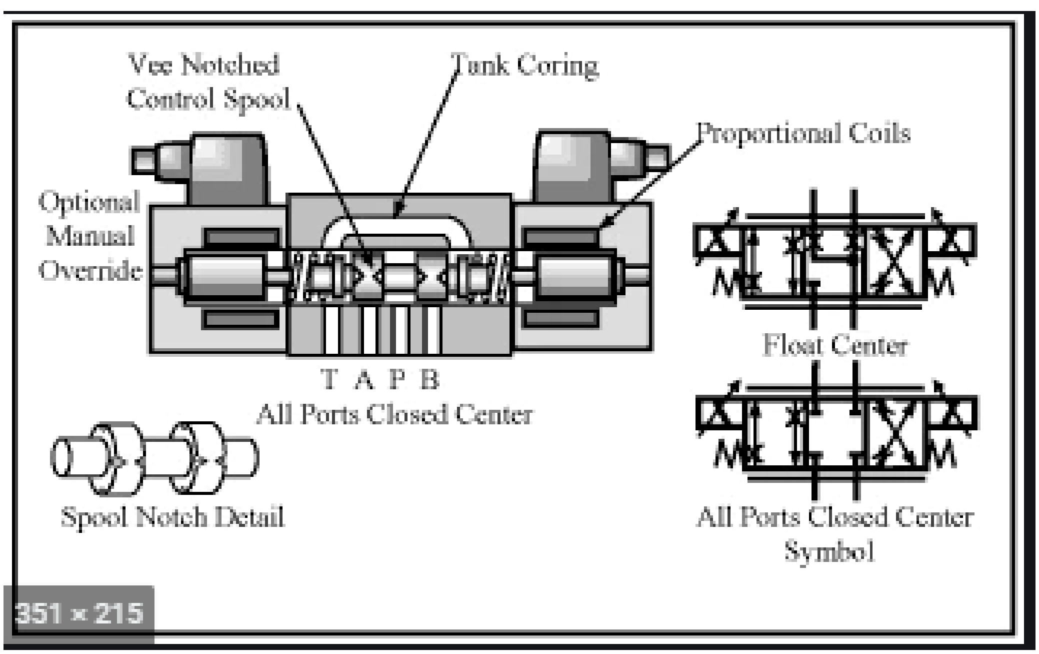
The time delay can be extended with the addition of external reservoir. Time delay valve, NC type. The constructions of an on-delay timer (NC) type in the normal and actuated are shown in Figure It can be seen that 3/2 DCV operates in the on delay mode permanently. But, in some designs, the valve can be operated in the off-delay mode by connecting the check valve in reverse direction. For this purpose, the ports of the throttle check valve should be brought out

SINGLE STAGE INFINITE POSITION VALVE

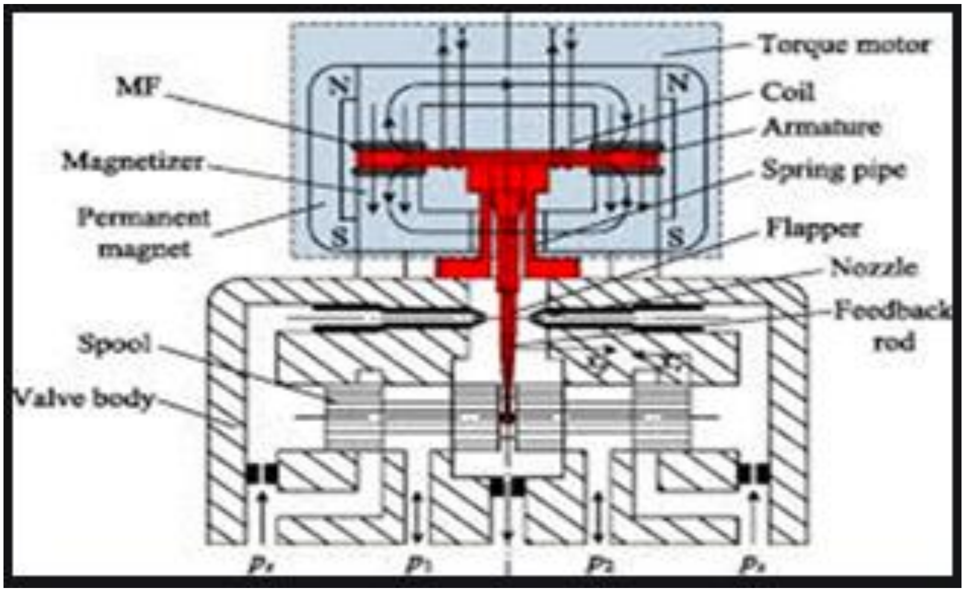
The directional control valves discussed so far in this series have all been configured to either pass full flow or completely block flow. The only way to decrease flow through these valves is by adding flow controls or by mechanically limiting movement of an internal part.

The first infinitely variable valve available was the servo valve. Internal flow-modifying parts could be moved to any position at any rate, so output from any port could be varied at will. (Some call these valves infinitely variable 4-way flow controls.) The main problem with servo valves was (and still is) that they require very clean fluid to keep them operating effectively. Fluid from a standard well-maintained hydraulic circuit contains enough contamination to cause most servo valves to fail in a matter of minutes or only last a few hours at best. This meant that the original servo valves were tried and removed from many machines that needed precise control but not at the perceived cost of cleaning up the hydraulic oil.

Some actuators must move at a precise speed, stop at a close-tolerance position, or produce a very accurate force to perform the work for which they were designed. With the proper input signals and feedback devices, proportional or servo valves can make an actuator perform any or all these functions flawlessly.



FLAPPER JET SERVO VALVE



MODULE 4

ACTUATORS-LINEAR ACTUATOR- PRINCIPLE OF OPERATION

A **linear actuator** is an actuator that creates motion in a straight line, in contrast to the circular motion of a conventional electric motor. Linear actuators are used in machine tools and industrial machinery, in computer peripherals such as disk drives and printers, in valves and dampers, and in many other places where linear motion is required. Hydraulic or pneumatic cylinders inherently produce linear motion. Many other mechanisms are used to generate linear motion from a rotating motor.

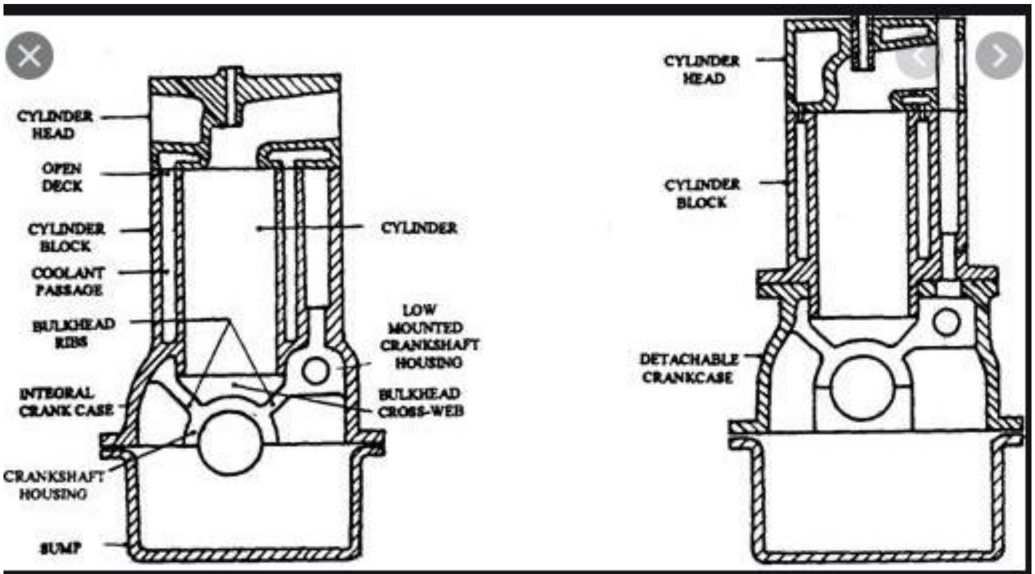
Mechanical linear actuators typically operate by conversion of rotary motion into linear motion. Conversion is commonly made via a few simple types of mechanism:

- **Screw**:, screw jack, ball screw and roller screw actuators all operate on the principle of the simple machine known as the screw. By rotating the actuator's nut, the screw shaft moves in a line.
- **Wheel and axle**: Hoist, winch, rack and pinion, chain drive, belt drive, rigid chain and rigid belt actuators operate on the principle of the wheel and axle. A rotating wheel moves a cable, rack, chain or belt to produce linear motion.[1]
- **Cam**: Cam actuators function on a principle similar to that of the wedge, but provide relatively limited travel. As a wheel-like cam rotates, its eccentric shape provides thrust at the base of a shaft.

Some mechanical linear actuators only pull, such as hoists, chain drive and belt drives. Others only push (such as a cam actuator). Pneumatic and hydraulic cylinders, or lead screws can be designed to generate force in both directions.

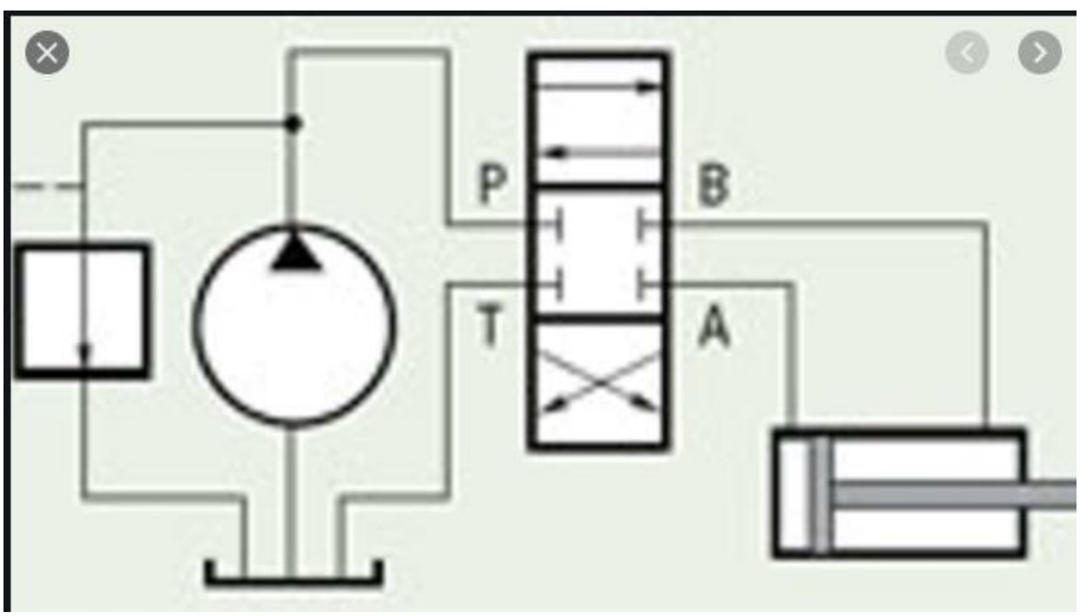
Mechanical actuators typically convert rotary motion of a control knob or handle into linear displacement via screws and/or gears to which the knob or handle is attached. A jackscrew or car jack is a familiar mechanical actuator. Another family of actuators are based on the segmented spindle. Rotation of the jack handle is converted mechanically into the linear motion of the jack head. Mechanical actuators are also frequently used in the field of lasers and optics to manipulate the position of linear stages, rotary stages, mirror mounts, goniometers and other positioning instruments. For accurate and repeatable positioning, index marks may be used on control knobs. Some actuators include an encoder and digital position readout. These are similar to the adjustment knobs used on micrometers except their purpose is position adjustment rather than position measurement.

SIMPLE CYLINDER



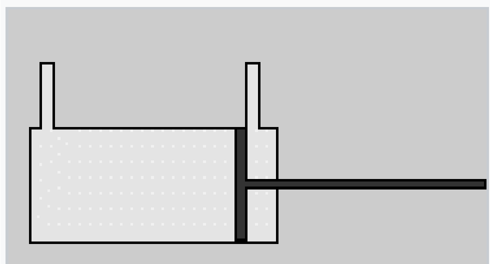
CYLINDER WITH EQUAL EXTEND/ RETRACT FORCE

Double rod-end cylinders are useful for moving two loads simultaneously, and they also eliminate the differential area between the rod side and blank side of the piston. With equal areas (and cylinder volumes) on both sides of the piston, a given flow produces the same extension and retraction speeds.



SINGLE ACTING CYLINDER

A **single-acting cylinder** in a reciprocating engine is a cylinder in which the working fluid acts on one side of the piston only. A single-acting cylinder relies on the load, springs, other cylinders, or the momentum of a flywheel, to push the piston back in the other direction. Single-acting cylinders are found in most kinds of reciprocating engine. They are almost universal in internal combustion engines (e.g. petrol and diesel engines) and are also used in many external combustion engines such as Stirling engines and some steam engines. They are also found in pumps and hydraulic rams.



Double-acting hydraulic cylinder

CYLINDER SPEED CALCULATION

Over the past several months, we have noticed that one of our hydraulic cylinders speeds up by itself intermittently. Would you have any idea as to why this is happening and if this is a common problem?"

An increase in hydraulic cylinder speed is a rare occurrence. To better understand the problem, let’s consider the much more prevalent case of decreasing speed and apply the opposite logic.

In terms of hydraulic systems, a reduction in performance is usually the first clue that a problem has manifested in the system. This is most often indicated by longer cycle times and slower operation.

The root cause of these failure symptoms can frequently be traced back to fluid flow. The fluid flow in a hydraulic system determines actuator speed and quickness of response. Loss of flow will equate to loss of speed.

Applying this same logic to an increased cylinder speed would mean that more flow is occurring. What could happen in a hydraulic system that would cause an increase in flow over time?

- Internal leakage – If an internal leak becomes clogged, the flow would inherently increase.

- Viscosity change — If the viscosity were to decrease, the flow would increase (depending on the pump and system design).
- Filter collapse or bypass malfunction — If the filter was causing reduced flow and then burst, or there was a malfunction with the bypass that allowed flow to increase, both would result in an increased cylinder speed.
- Air entrainment — Air in the fluid will cause poor (slow) performance. If the air problem is corrected, the system will speed up.
- Oil line cleared — If a restricted or blocked oil line becomes unrestricted/unblocked, the fluid flow will increase.
- Change in load — If the load on the cylinder is reduced, it may increase cylinder speed.

These are just a few things that may be plaguing the hydraulic system. In order to provide a more comprehensive diagnosis, more details would need to be known, such as the system design, seal health, filter type and age, contamination levels, cylinder position, etc.

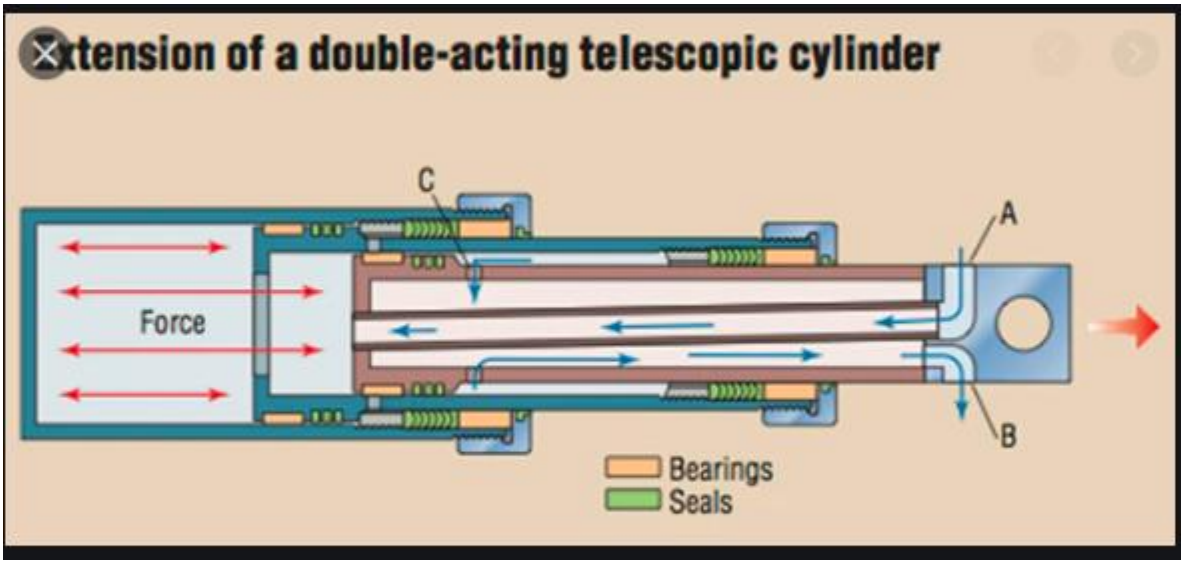
Keep in mind that not all hydraulic cylinders are created equal. It is estimated that up to 25 percent of mechanical equipment failures are design related. In regards to hydraulic cylinders, this suggests as many as one in four are not adequately designed for the application in which they are operating. So if the hydraulic cylinder suffers recurring failure, it is likely that design modifications are required to break the circle of failure and repair.

CONSTRUCTION DETAILS OF CYLINDER

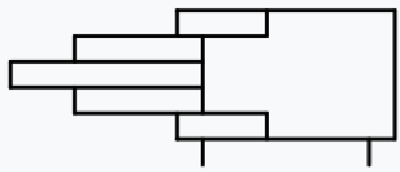
Furthermore, the head is attached to the top surface of the cylinder block with studs/bolts. A gasket is used between the head and the block to provide a seal to prevent leakage of gases. Besides, the block also has ports, oil passages and water jackets carved inside it to provide lubrication and cooling. However, some cylinder blocks also house camshaft & have provisions to mount the related parts.

Moreover, the L-head engine blocks also contain openings for the valves & valve ports. The bottom of the block supports the crankshaft and also the oil pan. In most engines, the block also supports the camshaft through bushings that fit into machined holes. In some engines, the intake and exhaust manifolds are attached to the sides of the block. Other parts fitted to the block include the water pump, timing gear (both at the front) and flywheel, clutch housing (both at rear). They also include ignition, distributor, and fuel pump.

TWO STAGE TELESCOPIC PISTON



Telescopic cylinders are a special design of a hydraulic cylinder or pneumatic cylinder as well as pulley system which provide an exceptionally long output travel from a very compact retracted length. Typically the collapsed length of a telescopic cylinder is 20 to 40% of the fully extended length depending on the number of stages. Some pneumatic telescoping units are manufactured with retracted lengths of under 15% of overall extended unit length. This feature is very attractive to machine design engineers when a conventional single stage rod style actuator will not fit in an application to produce the required output stroke.



Heavy duty telescopic cylinders are usually powered by oil hydraulics, whereas some lighter duty units could also be powered by compressed air.

Telescopic cylinders are also referred to as telescoping cylinders and multi-stage telescopic cylinders.

An application for telescopic cylinders commonly seen is that of the dump body on a dump truck used in a construction site. In order to empty the load of gravel completely, the dump body must be raised to an angle of about 60 degrees. To accomplish this long travel with a conventional hydraulic cylinder is very difficult considering that the collapsed length of a single stage rod cylinder is approximately 110% of its output stroke.[1] It would be very challenging for the design engineer to fit the single stage cylinder into the chassis of the dump truck with the dump body in the horizontal rest position. This task is easily accomplished, however, using a telescopic style multi-stage cylinder.

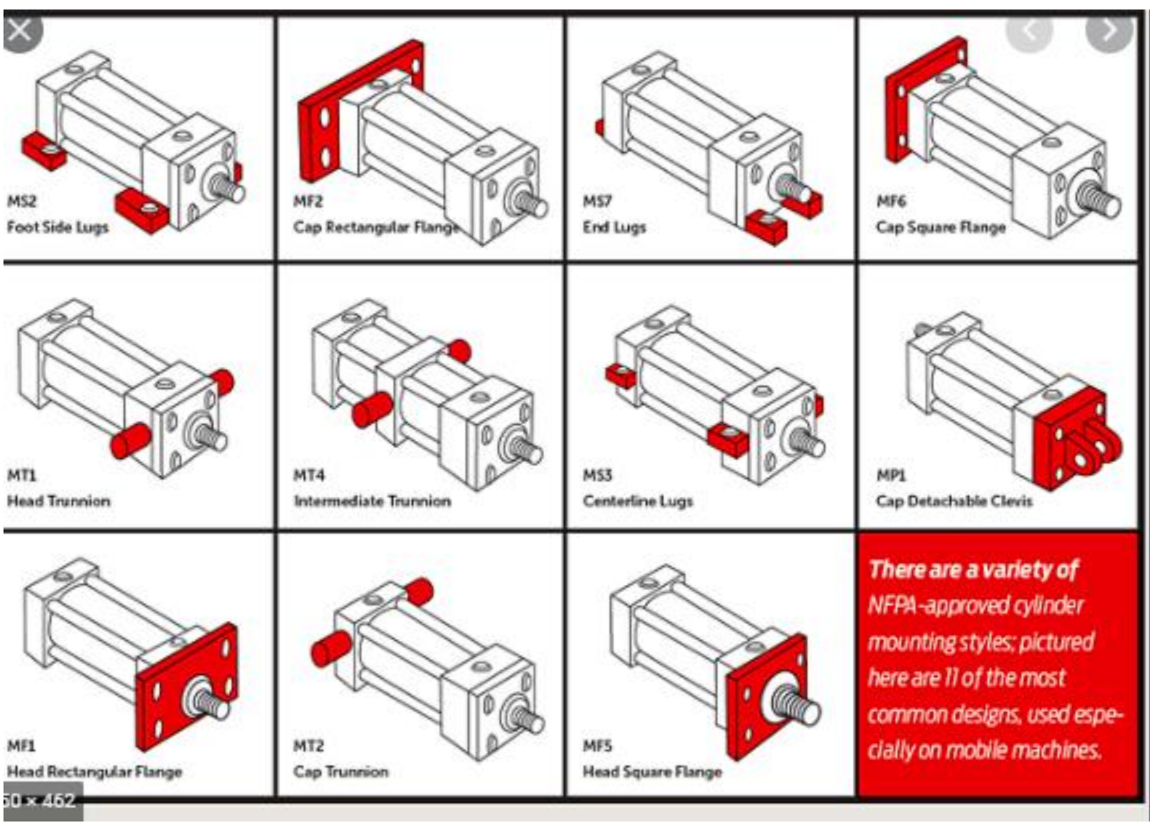
IMPACT CYLINDER

Pneumatic cylinder(s) (sometimes known as **air cylinders**) are mechanical devices which use the power of compressed gas to produce a force in a reciprocating linear motion.

Like hydraulic cylinders, something forces a piston to move in the desired direction. The piston is a disc or cylinder, and the piston rod transfers the force it develops to the object to be moved.[1] :85 Engineers sometimes prefer to use pneumatics because they are quieter, cleaner, and do not require large amounts of space for fluid storage.

Because the operating fluid is a gas, leakage from a pneumatic cylinder will not drip out and contaminate the surroundings, making pneumatics more desirable where cleanliness is a requirement. For example, in the mechanical puppets of the Disney Tiki Room, pneumatics are used to prevent fluid from dripping onto people below the puppets.

MOUNTING OF CYLINDERS



ROTARY ACTUATORS

A **rotary actuator** is an actuator that produces a rotary motion or torque.

The simplest actuator is purely mechanical, where linear motion in one direction gives rise to rotation. The most common actuators are electrically powered; others may be powered pneumatically or hydraulically, or use energy stored in springs.

The motion produced by an actuator may be either continuous rotation, as for an electric motor, or movement to a fixed angular position as for servomotors and stepper motors. A further form, the torque motor, does not necessarily produce any rotation but merely generates a precise torque which then either causes rotation or is balanced by some opposing torque.

Stepper motors

A variety of stepper motors

Main article: Stepper motor

Stepper motors are a form of electric motor that has the ability to move in discrete steps of a fixed size. This can be used either to produce continuous rotation at a controlled speed or to move by a controlled angular amount. If the stepper is combined with either a position encoder or at least a single datum sensor at the zero position, it is possible to move the motor to any angular position and so to act as a rotary actuator.

Servomotors

Radio control servo

Main article: servomotor

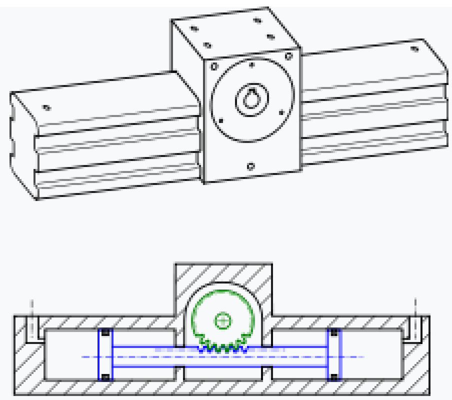
A servomotor is a packaged of several components: a motor (usually electric, although fluid power motors may also be used), a gear train to reduce the many rotations of the motor to a higher torque rotation, a position encoder that identifies the position of the output shaft and an inbuilt control system. The input control signal to the servo indicates the desired output position. Any difference between the position commanded and the position of the encoder gives rise to an error signal that causes the motor and gear train to rotate until the encoder reflects a position matching that commanded.

A simple low-cost servo of this type is widely used for radio-controlled models.

Other types

A recent, and novel, form of ultra-lightweight actuator uses memory wire. As a current is applied, the wire is heated above its transition temperature and so changes shape, applying a torque to the output shaft. When power is removed, the wire cools and returns to its earlier shape.[1]

Fluid power actuators



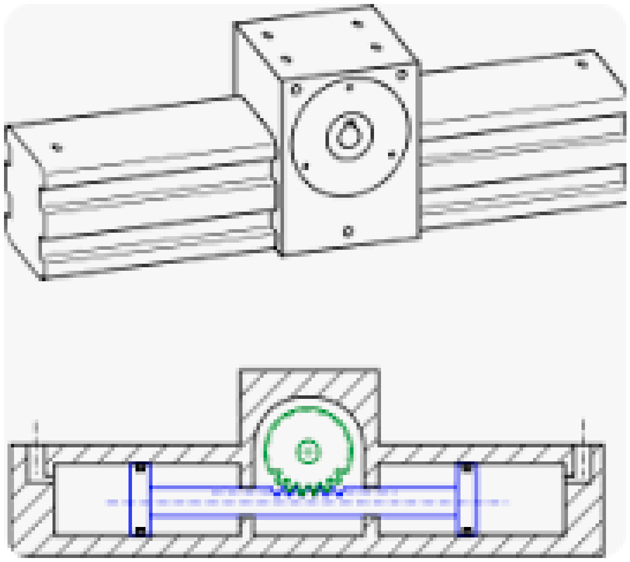
Hydraulic or pneumatic rotary actuator, using a rack and pinion

Both hydraulic and pneumatic power may be used to drive an actuator, usually the larger and more powerful types. As their internal construction is generally similar (in principle, if not in size) they are often considered together as fluid power actuators.[2] Fluid power actuators are of two common forms: those where a linear piston and cylinder mechanism is geared to produce rotation (illustrated) and those where a rotating asymmetrical vane swings through a cylinder of two different radii. The differential pressure between the two sides of the vane gives rise to an unbalanced force and thus a torque on the output shaft.[2] Vane actuators require a number of sliding seals and the joints between these seals have tended to cause more problems with leakage than for the piston and cylinder type.

Vacuum actuators

Where a supply of vacuum is available, but not pneumatic power, rotary actuators have even been made to work from vacuum power. The only common instance of these was for early automatic windscreen wipers on cars up until around 1960. These used the manifold vacuum of a petrol engine to work a quarter-turn oscillating vane actuator. Such windscreen wipers worked adequately when the engine was running under light load, but they were notorious that when working hard at top speed or climbing a hill, the manifold vacuum was reduced and the wipers slowed to a crawl

LIMITED MOTION ROTARY ACTUATORS



A rotary actuator is an actuator that produces a rotary motion or torque. The simplest actuator is purely mechanical, where linear motion in one direction gives rise to rotation. The most common actuators are electrically powered; others may be powered pneumatically or hydraulically, or use energy stored in springs.

SPEED CONTROL OF ACTUATORS

It is frequently helpful to know the basic practices for controlling pneumatic actuator speed, as well as a few guidelines for gathering the information to properly select the components.

If you are looking to control the speed of the pneumatic actuator in your application, the most effective way is to use a speed control valve or flow control valve to vary the amount of flow out of the exhaust port of the actuator.

In order to adjust the speed, the flow must be controlled, where as adjusting the force of the actuator should be handled by controlling the pressure. Adjusting the pressure may have an effect on the speed, but is not a recommended method to control the speed.

To maintain a constant speed for your pneumatic actuator, size a fixed orifice for a constant flow on the exhaust port of the pneumatic actuator in conjunction with a pressure regulator on the input. The pressure regulator will ensure that the output pressure will remain constant (relatively) given a varying input pressure. The fixed orifice will maintain the desired flow to maintain the proper speed for your pneumatic actuator.

n order to properly size a flow control valve, you will need 3 things:

- A maximum pressure
- Thread size
- Tube size

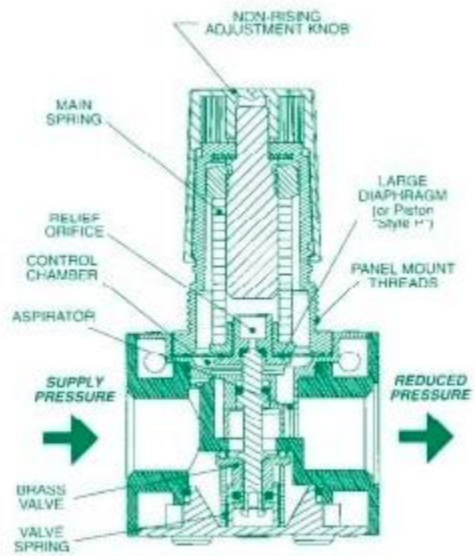
Armed with this information, you can now select the proper valve for your application. These valves can be installed directly into actuator ports, directly installed into the valve exhaust ports, or simply installed into the exhaust line.

In order to size the fixed orifice properly, you will need to know the supply pressure, fitting size, and desired flow of the output. After calculating the fixed orifice size, try a few similar sizes to ensure that you are getting the desired result.
Once again, the fixed orifice should be installed on the exhaust port of the actuator or into the exhaust line.

To size the pressure regulator, you will need to know:

- The port size
- Threads
- Input pressure
- Output pressure
- Whether it needs to be relieving or non-relieving pressure regulator.

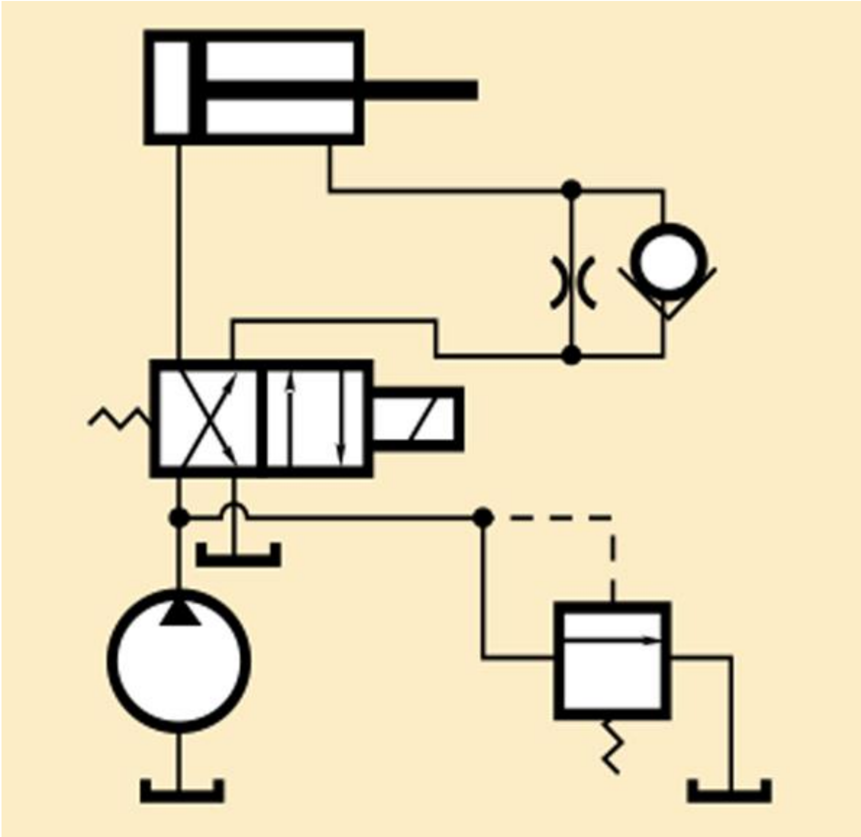
Pressure regulators should almost always be placed upstream of the control valve. If one needs to be installed between the valve and actuator, then one with bypass flow path should be used.



SPEED CONTROL BY PUMP VOLUME-METER IN SPEED CONTROL

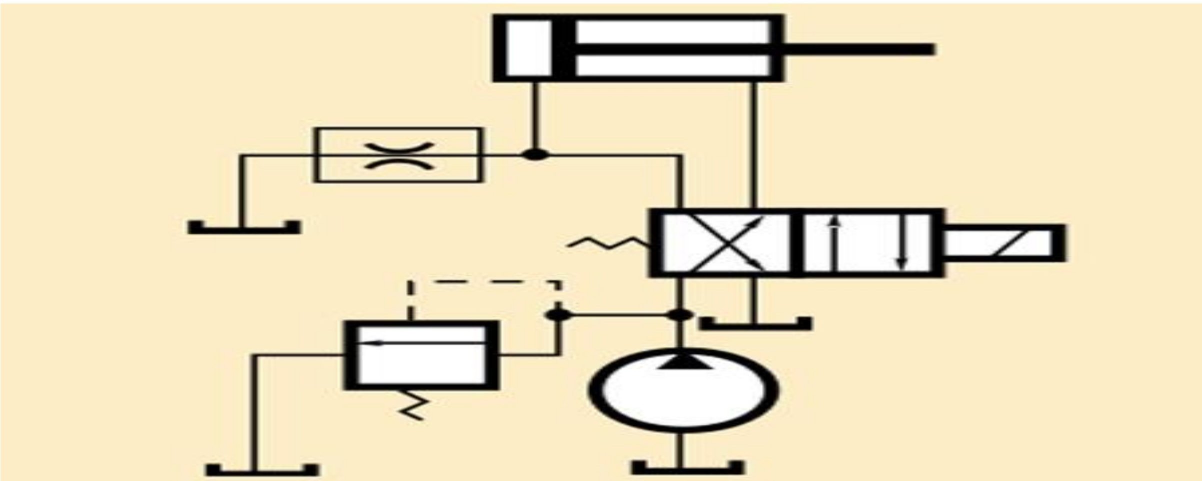
METER OUT SPEED CONTROL FOR OVERHAULING LOAD

Speed control during a work stroke can be accomplished by regulating flow *to* the cylinder. The check valve allows free reverse flow when the cylinder retracts. It normally gives finer speed control than a meter-out circuit.



Meter-out circuit

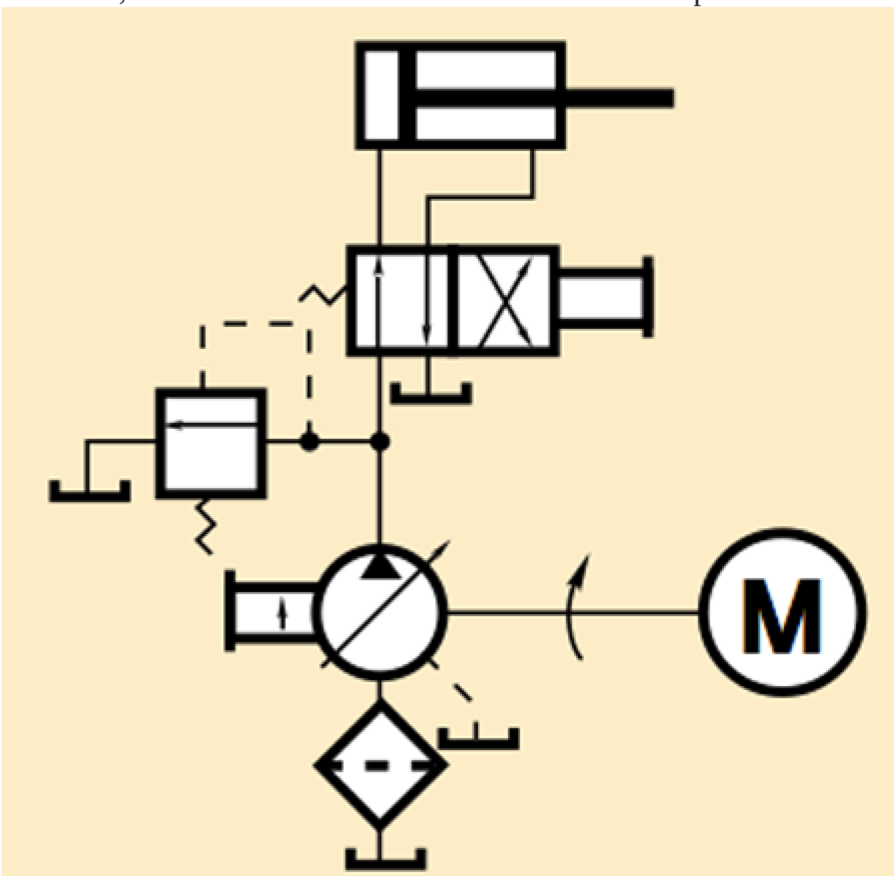
Regulating flow *from* the cylinder is another way to control speed. This circuit maintains a constant backpressure during rod extension and prevents lunging if the load drops quickl reverses.



BLEED OFF SPEED CONTROL

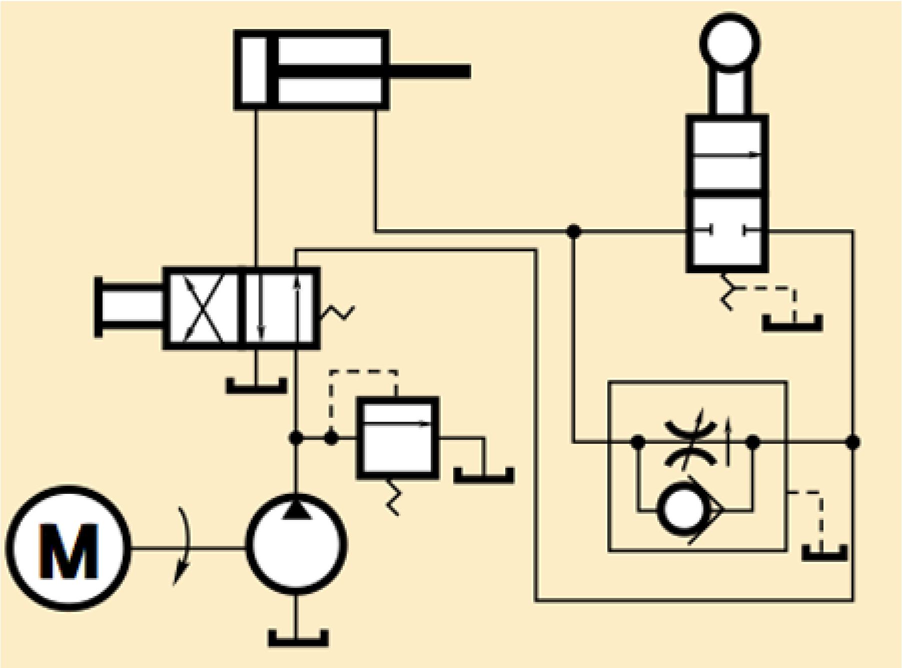
Bleed-off circuit

Flow to the cylinder is regulated by metering part of the pump flow to tank. This circuit is more efficient than meter-in or meter-out, as pump output is only high enough to overcome resistance. However, it does not compensate for pump slip.



Variable-volume pump

Pump flow can be controlled by various means such as manual, electric motor, hydraulic, or mechanical. How closely flow output actually matches command depends, in part, on slip, which increases with load. With a pressure-compensated, variable-volume pump, output flow decreases with the increasing pressure. This type of pump can be used for traverse and clamp operations. An external relief valve is usually unnecessary when a pressure-compensated pump is used. For details on the different types of pumps, their operation, and how they vary flow, refer to the pumps section of this Handbook.



Variable feed

Many machines require intermittent fast and slow feed during their cycles. This can be accomplished by having a cam-operated 2-way valve in parallel with a meter-out flow control valve. Rapid forward movement takes place any time the 2-way valve is open. Closing off the valve slows down cylinder speed. Properly positioning the cams obtains the required speeds in sequence. The check valve in parallel with the flow control permits free return flow, allowing the cylinder rod to return rapidly.

MODULE 5

PROCESS CONTROL PNEUMATICS

Process control valves and actuators

In most pneumatic process control schemes, the final actuator controls the flow of a fluid. Typical examples are liquid flow for chemical composition control, level control, fuel flow for temperature control and pressure control. In most cases the actual control device will be a pneumatically actuated flow control valve.

Even with totally electronic or computer-based process control schemes, most valves are pneumatically operated. Although electrically operated actuators *are* available, pneumatic devices tend to be cheaper, easier to maintain and have an inherent, and predictable, failure mode.

It is first useful to discuss the way in which fluid flow can be controlled. It is, perhaps, worth noting that these devices give full proportional control of fluid flow, and are *not* used to give a simple flow/no-flow control.

1. **FLOW CONTROL VALVES**
2. **LOW CONTROL VALVES**

All valves work by putting a variable restriction in the flow path. There are three basic types of flow control valves, shown in Figures 7.12–7.14.

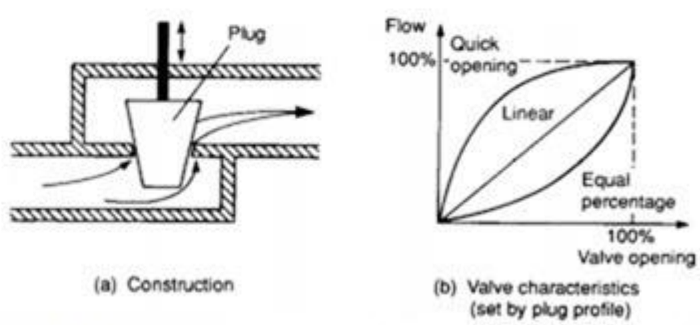


FIGURE 7.12 The plug valve

Of these the plug or globe valve (Figure 7.12) is probably most common. This controls flow by varying the vertical plug position, which alters the size of the orifice between the tapered plug and valve seat. Normally the plug is guided and con- strained from sideways movement by a cage, not shown in Figure 7.12a for simplicity

.

The valve characteristics define how the valve opening controls flow. The characteristics of the globe valve can be accurately predetermined by machining the taper of the plug. There are three common characteristics, shown in Figure 7.12b. These are specified for a constant pressure drop across the valve, a condition which rarely occurs in practical plants. In a given installation, the flow through a valve for a given opening depends not only on the valve, but also on pressure drops from all the other items and the piping in the rest of the system. The valve characteristic (quick opening, linear, or equal percentage) is therefore chosen to give an approximately linear flow/valve position relationship for this particular configuration.

A butterfly valve, shown in Figure 7.13, consists of a large disc which is rotated inside the pipe, the angle determining the restriction. Butterfly valves can be made to any size and are widely

used for control of gas flow. They do, how- ever, suffer from rather high leakage in the shut-off position and suffer badly from dynamic torque effects, a topic discussed later.
The ball valve, shown in Figure 7.14, uses a ball with a through hole which is rotated inside a machined seat. Ball valves have an excellent shut-off characteristic with leakage almost as good as an on/off isolation valve.

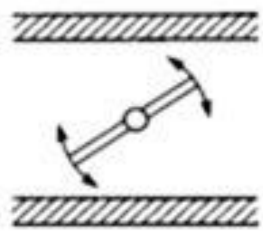


FIGURE 7.13 The butterfly valve

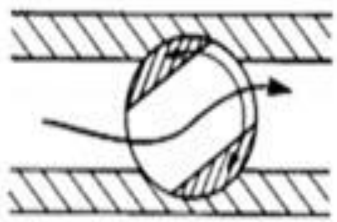


FIGURE 7.14 The ball valve

When fluid flows through a valve, dynamic forces act on the actuator shaft. In Figure 7.15a, the flow assists opening (and opposes the closing) of the valve. In Figure 7.15b, the flow assists the closing (and opposes the opening) of the valve. The latter case is particularly difficult to control at low flows as the plug tends to slam into the seat. This effect is easily observed by using the plug and chain to control flow of water out of a household bath.

The balanced valve of Figure 7.15c uses two plugs and two seats with opposite flows and gives little dynamic reaction onto the actuator shaft. This is achieved at the expense of higher leakage, as manufacturing tolerances cause one plug to seat before the other.

Butterfly valves suffer particularly from dynamic forces, a typical example being shown in Figure 7.16. As can be seen, maximum force occurs just before the fully open position, and this force acts to open the valve. It is not unknown for an actuator to be unable to move a butterfly valve off the fully open position and it is consequently good practice to mechanically limit opening to about 60°.

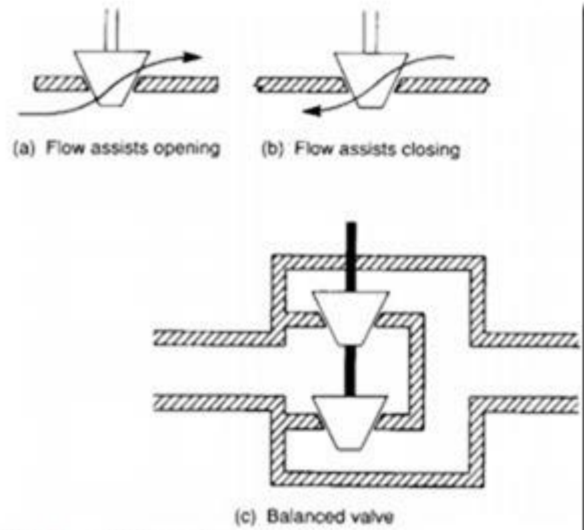


FIGURE 7.15 Dynamic forces acting on a valve

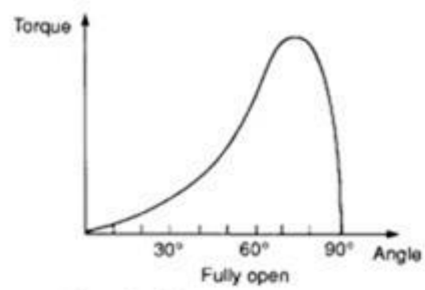


FIGURE 7.16 Torque on a butterfly valve

ACTUATORS

The globe valve of Figure 7.12 needs a linear motion of the valve stem to control flow, whereas the butterfly valve of Figure 7.13 and the ball valve of Figure 7.14 require a rotary motion. In practice all, however, use a linear displacement actuator – with a mechanism similar to that in Figure 7.17 used to convert a linear stroke to an angular rotation if required.

Pneumatic valve actuators are superficially similar to the linear actuators of Chapter 5, but there are important differences. Linear actuators operate at a constant pressure, produce a force proportional to applied pressure and are generally fully extended or fully retracted. Valve actuators operate with an applied pressure which can vary from, say, 0.2 to 1 bar, producing a displacement of the shaft in direct proportion to the applied pressure.

A typical actuator is shown in Figure 7.18. The control signal is applied to the top of a piston sealed by a flexible diaphragm. The downward force from this pressure ($P \times A$) is opposed by the spring compression force and the piston settles where the two forces are equal, with a displacement proportional to applied pressure. Actuator gain (displacement/pressure) is determined by the stiff- ness of the spring, and the pressure at which the actuator starts to move (0.2 bar say) is set by a pre-tension adjustment.

Figure 7.18b illustrates the action of the rubber diaphragm. This 'peels' up and down the cylinder wall so the piston area remains constant over the full range of travel.
The shaft of the actuator extends for increasing pressure, and fails in a fully up position in the event of the usual failures of loss of air supply, loss of signal or rupture of the diaphragm seal. For this reason such an actuator is known as a fail-up type.

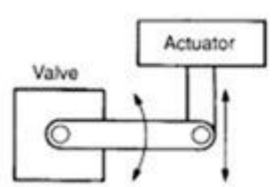


FIGURE 7.17 Conversion from linear actuator motion to rotary valve motion

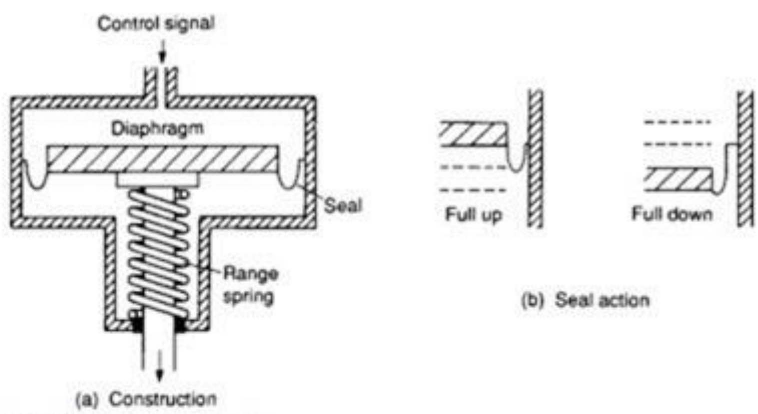


FIGURE 7.18 Fail-up actuator

In the actuator of Figure 7.19, on the other hand, signal pressure is applied to the bottom of the piston and the spring action is reversed. With this design the shaft moves up for increasing pressure and moves down for common failure modes. This is known as a fail-down or reverse-acting actuator.

One disadvantage of this design is the need for a seal on the valve shaft.
Where safety is important, valve and actuator should be chosen to give the correct failure mode. A fuel valve, for example, should fail closed, while a cool- ing water valve should fail open.
Valve actuators tend to have large surface areas to give the required force, which means a significant volume of air is above the piston. Valve movement leads to changes in this volume, requiring air to be supplied from, or vented by, the device providing the pressure signal. A mismatch between the air requirements of the actuator and the capabilities of the device supplying pressure signal results in a slow, first-order lag response.

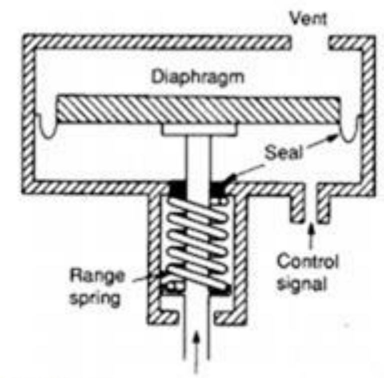


FIGURE 7.19 Fail-down actuator

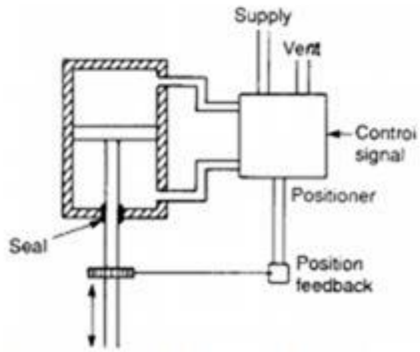


FIGURE 7.20 Double-acting cylinder (holds position on failure)

The net force acting on the piston in Figures 7.18 and 7.19 is the sum of force from the applied pressure, the opposing spring force *and* any dynamic forces induced into the valve stem from the fluid being controlled. These dynamic forces therefore produce an offset error in valve position. The effect can be reduced by increasing the piston area or the operating pressure range, but there are limits on actuator size and the strength of the diaphragm seal. In Figure 7.20 a double-acting piston actuator operating at high pressure is shown. There is no restoring spring, so the shaft is moved by application of air to, or venting of air from, the two sides of the piston. A closed loop position control scheme is used, in which shaft displacement is compared with desired displacement (i.e. signal pressure) and the piston pressures adjusted accordingly. The arrangement of Figure 7.20 is called a valve positioner, and correctly positions the shaft de- spite dynamic forces from the valve itself.

VALVE POSITIONERS

A valve positioner is used to improve the performance of a pneumatically operated actuator, by adding a position control loop around the actuator as shown in Figure 7.21. They are mainly used:
• to improve the operating speed of a valve;
• to provide volume boosting where the device providing the control signal can only provide a limited volume of air. As noted previously a mismatch

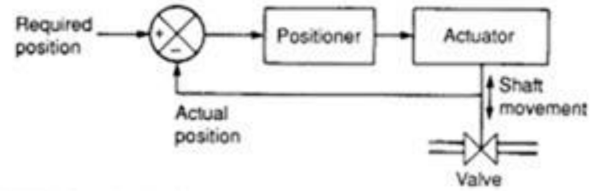


FIGURE 7.21 The valve positioner

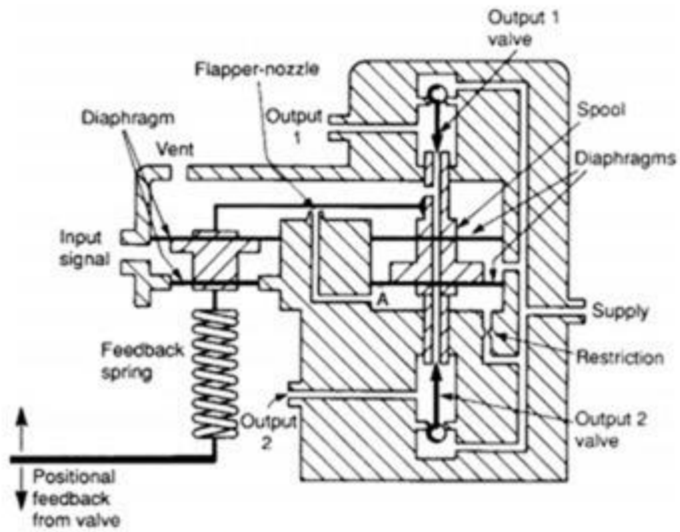


FIGURE 7.22 Force balance valve positioner

between the capabilities of driver and the requirements of an actuator results in a first-order lag response with a long time constant;

- to remove offsets resulting from dynamic forces in the valve (described in the previous section);
- where a pressure boost is needed to give the necessary actuator force;
- where a double-acting actuator is needed (which cannot be controlled with a single pressure line).

There are two basic types of valve positioner. Figure 7.22 shows the construction of a valve positioner using a variation of the force balance principle de- scribed earlier. The actuator position is converted to a force by the range spring. This is compared with the force from the signal pressure acting on the input diaphragm. Any mismatch between the two forces results in movement of the beam and a change in the flapper-nozzle gap.

If the actuator position is low, the flapper-nozzle gap decreases, causing a rise in pressure at point A. This causes the spool to rise, connecting supply air to output 1, and venting output 2, resulting in the lifting of the actuator. If actuator position is high, the flapper-nozzle gap increases and pressure at A falls, causing the spool to move down applying air to output 2 and venting output 1, which results in the actuator lowering. The actuator thus balances when the range spring force (corresponding to actuator position) matches the force from the input signal pressure (corresponding to the required position), giving a con- stant flapper-nozzle gap.

The zero of the positioner is set by the linkage of the positioner to the valve shaft and the range by the spring stiffness. Fine zero adjustment can be made by a screw at the end of the spring.

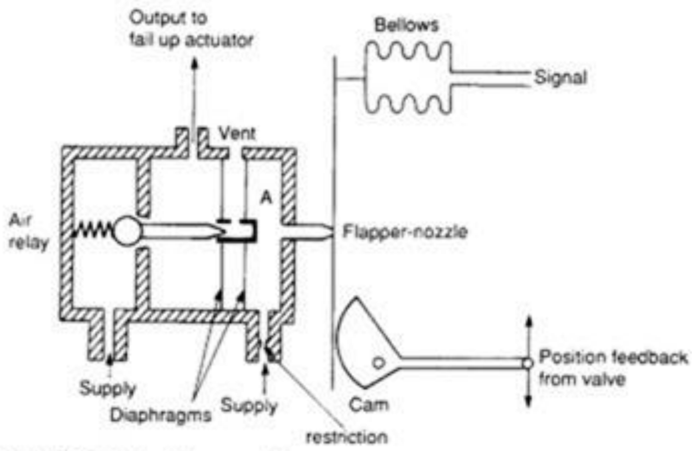


FIGURE 7.23 Motion balance positioner

The second type of positioner, illustrated in Figure 7.23, uses a motion balance principle. The valve shaft position is converted to a small displacement and applied to one end of the beam controlling the flapper-nozzle gap. The input signal is converted to a displacement at the other end of the beam. The pressure at A resulting from the flapper-nozzle gap is volume boosted by an air relay which passes air to, or vents air from, the actuator, to move the shaft until the flapper-nozzle gap is correct. At this point, the actuator position matches the desired position.

Positioners are generally supplied equipped with gauges to indicate supply pressure, signal pressure and output pressures, as illustrated in Figure 7.24 for a double-acting actuator.
Often, bypass valves are fitted to allow the positioner to be bypassed temporarily in the event of failure with the signal pressure sent directly to the actuator.

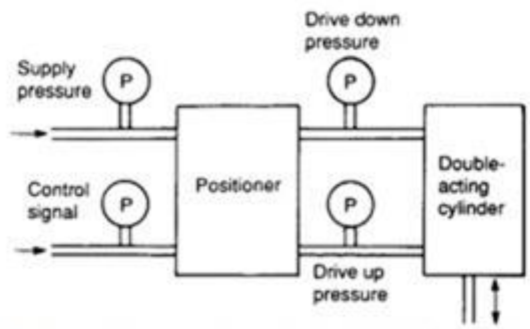


FIGURE 7.24 Pressure indication on a positioner for fault finding

THE FLAPPER NOZZLE

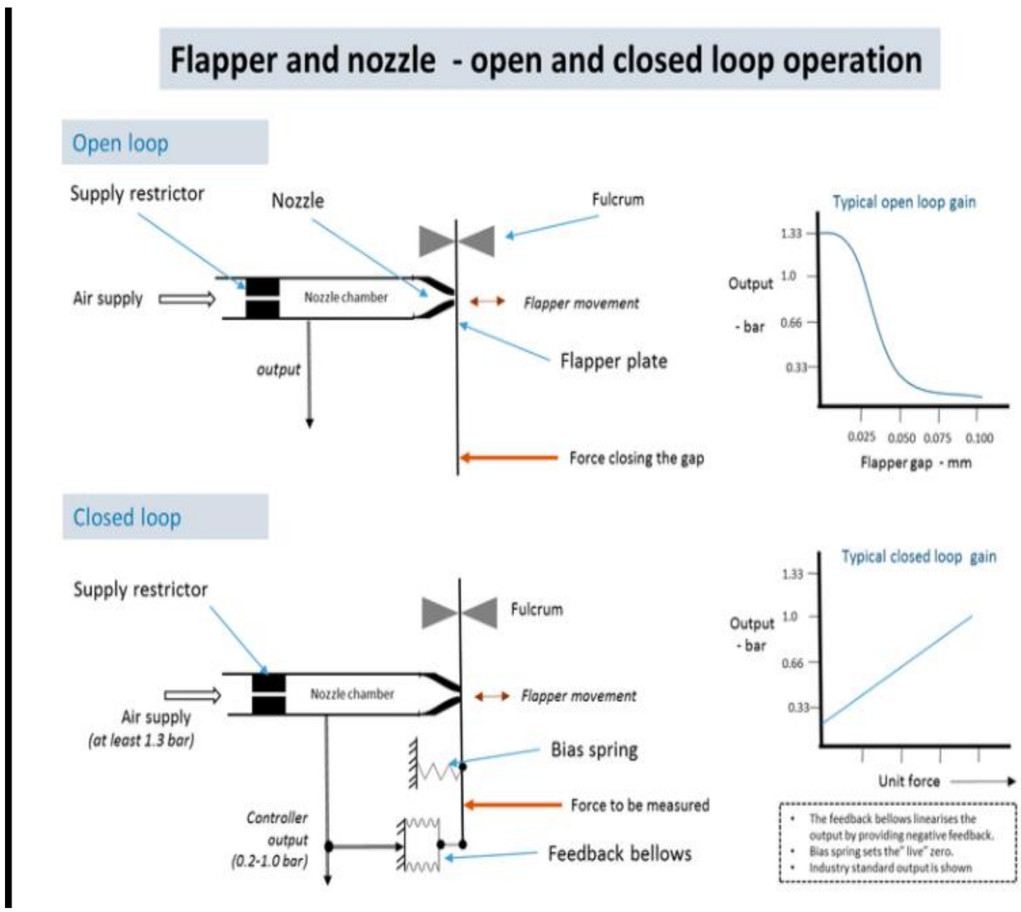
The nozzle and flapper mechanism is a displacement type detector which converts mechanical movement into a pressure signal, by covering the opening of a nozzle with a flat plate called the flapper.[1] This restricts fluid flow through the nozzle and generates a pressure signal.

It is a widely used mechanical means of creating a high gain fluid amplifier. In industrial control systems they played an important part in the development of pneumatic PID controllers and are still widely used today in pneumatic and hydraulic control and instrumentation systems.

The operating principle makes use of the high gain effect when a "flapper" plate is placed a small distance from a small pressurized nozzle emitting a fluid.

The example shown is pneumatic. At sub-millimeter distances a small movement of the flapper plate results in a large change in flow. The nozzle is fed from a chamber which is in turn fed by a restriction, so changes of flow result in changes of chamber pressure. The nozzle diameter must be larger than the restriction orifice in order to work.[2] The high gain of the open loop mechanism can be made linear using a pressure feedback bellows on the flapper to create a force balance system with a linear output. The "live" zero of 0.2 bar or 3 psi is set by the bias spring which ensures that the device is working in its linear region.

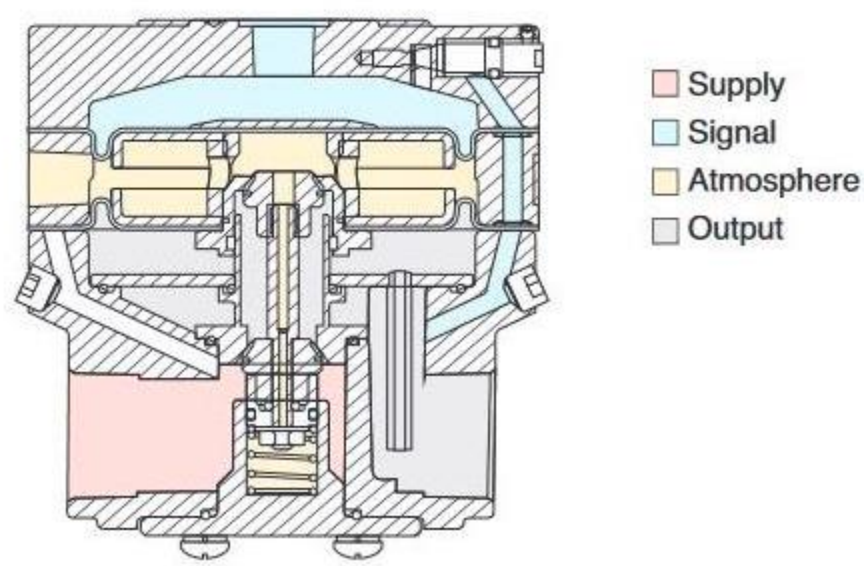
The industry standard ranges of either 3-15 psi (USA), or 0.2 - 1.0 bar (metric), is normally used in pneumatic PID controllers, valve positioning servomechanisms and force balance transducers.



VOLUME BOOSTER

In short, a volume booster is a pressure regulation device that is controlled by a pilot pressure instead of a spring or adjustment thread as in an air pressure regulator. A volume booster may also be called a "pilot operated regulator". The spring in a regulator normally supplies the mechanical pressure required to open the supply valve until there is an equal force balance between output pressure and spring force. In a volume booster, instead of a spring providing force balance, the "spring force" is supplied by a pilot pressure acting on a diaphragm. There are four basic air components to a volume booster circuit:

- Supply Pressure
- Regulated or downstream pressure
- Signal (pilot) Pressure
- Atmosphere (exhaust)



The signal or pilot pressure can be supplied by a regulator, I/P transducer, valve positioner or any other pressure modulating device.

The main purpose of a volume booster is to deliver a large volume of air downstream at a given pilot pressure. The output pressure can be modulated by the pilot pressure. Volume boosters are generally used in the following applications:

- To speed the stroke of larger volume actuators.
- Air operated remote pressure regulation.
- Hazardous environments where electric signals are not desirable.

Some common options for a volume booster include the addition of a bypass valve (bypass needle valve) which can be used to adjust the dynamic response to provide stable operation over a wide variety of applications. Another option could be the addition of an adjustable bias to skew the output pressure from the signal pressure. Although, this is generally found in smaller versions of a volume booster, sometimes referred to as an air relay. This could be a positive or negative bias. Other options could include special diaphragm materials for caustic and low temperature environments.

Please contact our technical support team for any questions regarding the use of a volume booster in your system.

AIR RELAY AND FORCE BALANCE

Air amplifiers balance input pressure and output pressure. An air relay, on the other hand (illustrated in Figure 7.5), balances input pressure with the force from a range spring. An increasing input signal causes air to pass from the supply to the load, while a decreasing input signal causes air to vent from the load. In the centre of the input signal range, there is no net flow to or from the output port

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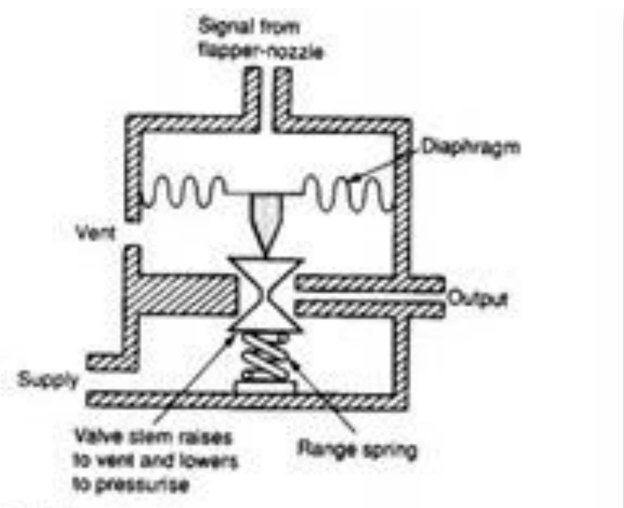


Figure 7.5 *The air relay*

An air relay is used to linearise a flapper-nozzle, as shown in Figure 7.6. Here, force from the unbalance in input pressures P1 and P2 is matched exactly by the force from the feedback bellows whose pressure is regulated by the air relay. Suppose flow in the pipe increases, causing pressure difference P1-P2 to increase. Increased force from the bellows at the top decreases the flapper gap causing pressure at the air relay input to

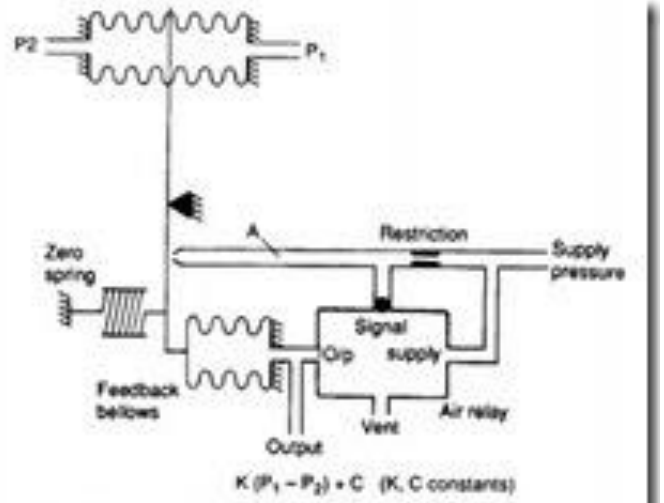


Figure 7.6 *The force balance principle*

rise. This causes air to pass to the feedback bellows, which apply a force opposite to that from the signal bellows. The system balances when the input pressure from the flapper nozzle to the air relay (point A) is at the centre of its range at which point the air relay neither passes air nor vents the feedback bellows.

This corresponds to a fixed flapper-nozzle gap.

Figure 7.6 thus illustrates an example of a feedback system where the pressure in the feedback bellows is adjusted by the air relay to maintain a constant flapper-nozzle gap. The force from the feedback bellows thus matches the force from the input signal bellows, and output pressure is directly proportional to (P1-P2). The output pressure, driven directly from the air relay, can deliver a large air volume.

The arrangement in Figure 7.6 effectively operates with a fixed flapper-nozzle gap. This overcomes the inherent non-linearity of the flapper-nozzle. It is known as the force balance principle and is the basis of most pneumatic process control devices.

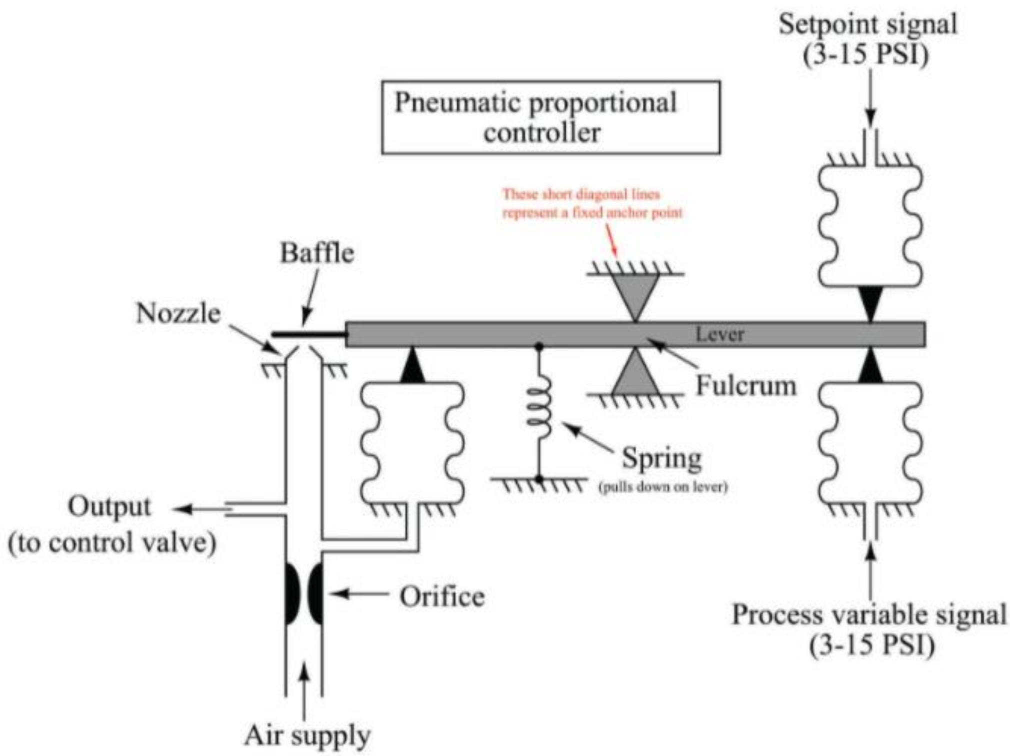
PNEUMATIC CONTROLLERS

A *pneumatic* controller receives a process variable (PV) signal as a variable air pressure, compares that signal against a desired set point (SP) value, and then mechanically generates another air pressure signal as the output, driving a final control element.

Throughout this section I will make reference to a pneumatic controller mechanism of my own design. This mechanism does not directly correspond to any particular manufacturer or model of pneumatic controller, but shares characteristics common to many. This design is shown here for the purpose of illustrating the development of P, I, and D control actions in as simple a context as possible

PROPORTIONAL PNEUMATIC CONTROL

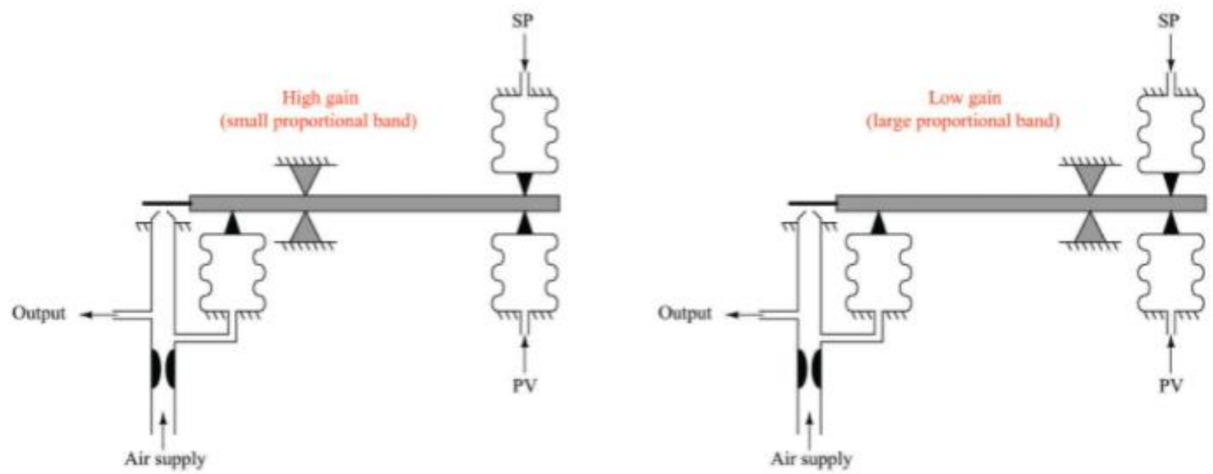
Many pneumatic PID controllers use the *force-balance* principle. One or more input signals (in the form of pneumatic pressures) exert a force on a beam by acting through diaphragms, bellows, and/or bourdon tubes, which is then counter-acted by the force exerted on the same beam by an output air pressure acting through a diaphragm, bellows, or bourdon tube. The self-balancing mechanical system "tries" to keep the beam motionless through an exact balancing of forces, the beam's position precisely detected by a nozzle/baffle mechanism:



The action of this particular controller is *direct*, since an increase in process variable signal (pressure) results in an increase in output signal (pressure). Increasing process variable (PV) pressure attempts to push the right-hand end of the beam up, causing the baffle to approach the nozzle. This blockage of the nozzle causes the nozzle's pneumatic backpressure to increase, thus increasing the amount of force applied by the output feedback bellows on the left-hand end of the beam and returning the flapper (very nearly) to its original position. If we wished to reverse the controller's action, all we would need to do is swap the pneumatic signal connections between the input bellows, so that the PV pressure was applied to the upper bellows and the SP pressure to the lower bellows.

Any factor influencing the ratio of input pressure(s) to output pressure may be exploited as a gain (proportional band) adjustment in this mechanism. Changing bellows area (either both the PV and SP bellows equally, and the output bellows by itself) would influence this ratio, as would a change in output bellows position (such that it pressed against the beam at some difference distance from the fulcrum point). Moving the fulcrum left or right is also an option for gain control, and in fact is usually the most convenient to engineer.

In this illustration the fulcrum is shown moved to two different positions, to effect a change in gain:



PROPORTIONAL PLUS INTEGRAL PNEUMATIC CONTROL

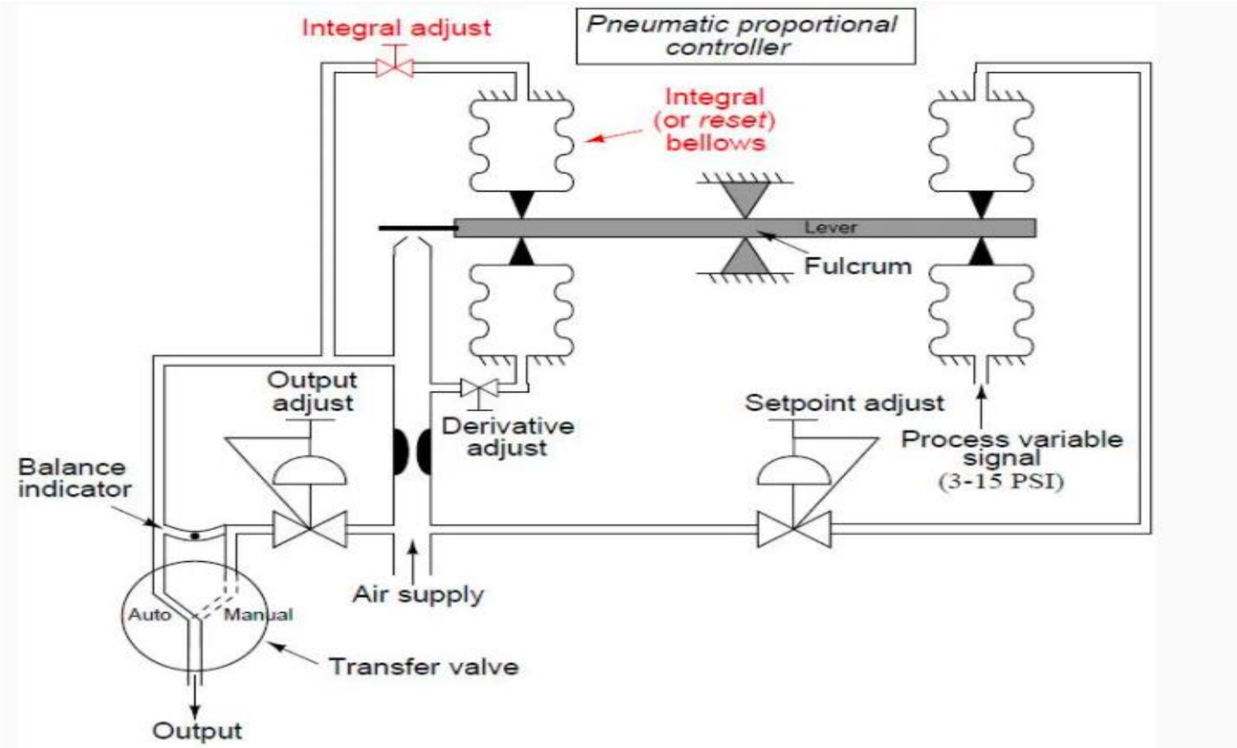
PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE PNEUMATIC CONTROL

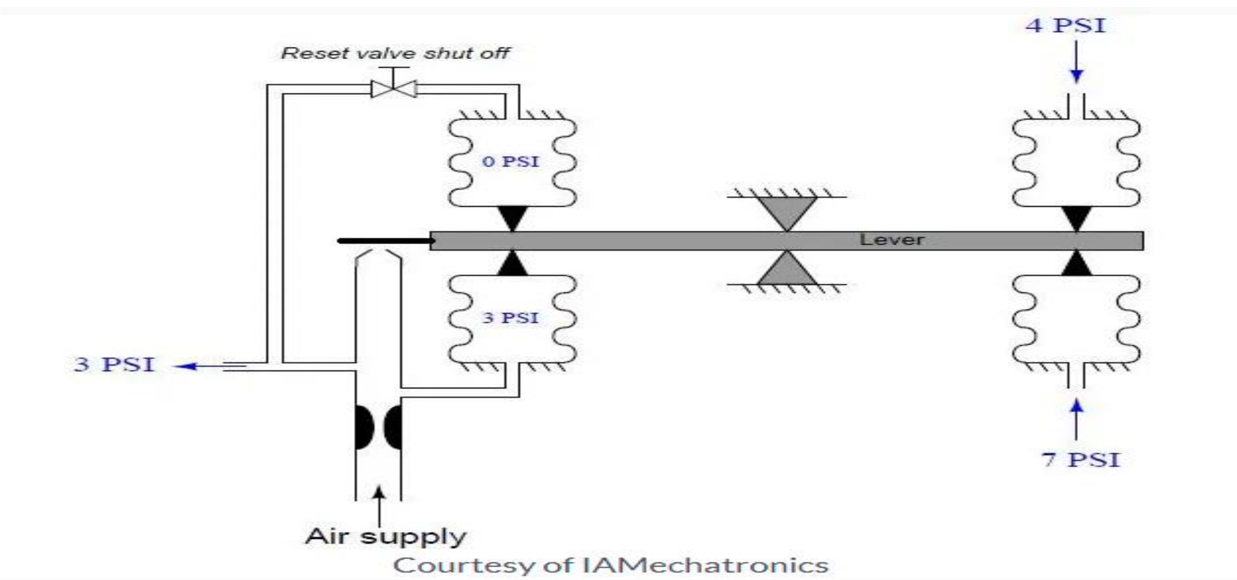
The pneumatic PID controller's integral element requires not only another restriction valve but also another bellow. These are called the *reset bellows,* and they should oppose the output feedback bellows, as you can see here.

This setup might seem counter-intuitive at first. However, this valve creates a delay in the filling of the reset bellows. Thus, the system works similarly to the resistor-capacitor (RC) circuit on an electronic controller.

As the reset bellows slowly fill with the output pressure, the change in pressure on the lever forces the output bellows to stay ahead of the reset bellows by constantly filling. Got it? No?

Okay, let's see how it works in practice.





CONVERTERS

The most common process control arrangement is probably electronic controllers with pneumatic actuators and transducers. Devices are therefore needed to convert between electrical analog signals and the various pneumatic standards. Electrical to pneumatic conversion is performed by an I–P converter, while pneumatic to electrical conversion is performed by a device called, not surprisingly, a P–I converter.

PI AND IP CONVERTERS

I-P CONVERTERS

Figure 7.25 illustrates a common form of I–P converter based on the familiar force balance principle and the flapper-nozzle. Electrical current is passed through the coil and results in a rotational displacement of the beam. The resulting pressure change at the flapper-nozzle gap is volume-boosted by the air relay and applied as a balancing force by bellows at the other end of the beam. A balance results when the force from the bellows (proportional to output pressure) equals the force from the coil (proportional to input electrical signal).

P-I CONVERTERS

The operation of a P–I converter, illustrated in Figure 7.26, again uses the force balance principle. The input pressure signal is applied to bellows and produces a deflection of the beam. This deflection is measured by a position transducer such as an LVDT (linear variable 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).

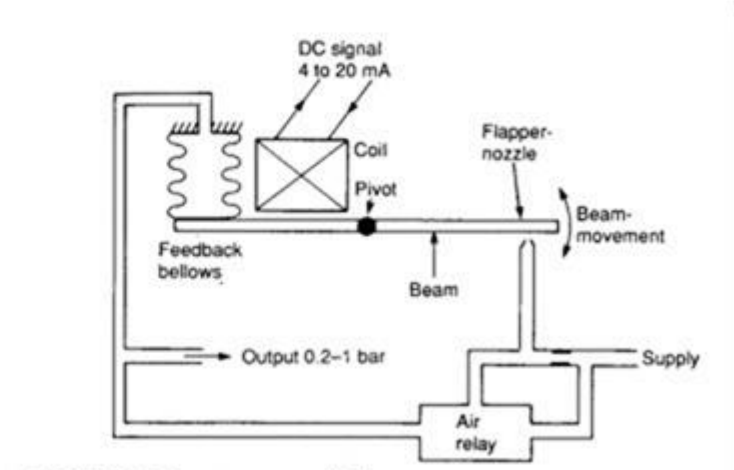


FIGURE 7.25 Current to pressure (I–P) converter

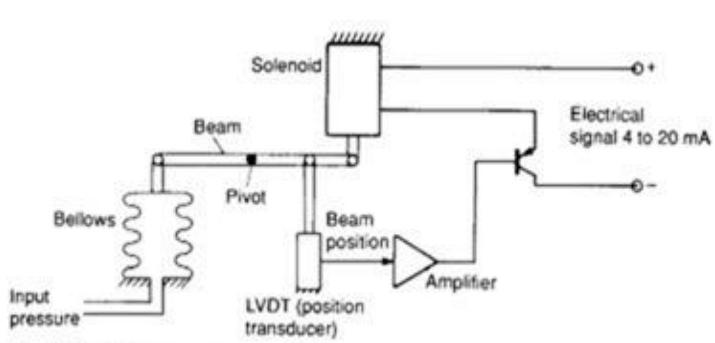


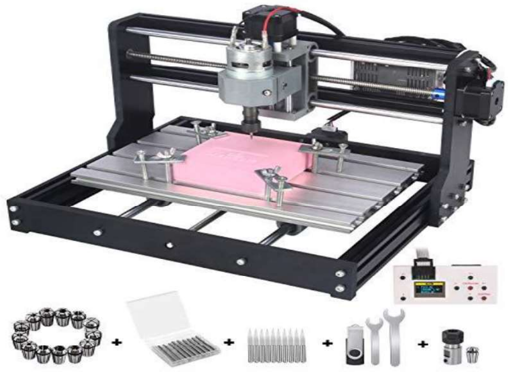
FIGURE 7.26 Pressure to current (P–I) converter

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 (e.g. 15–30 V). Often, the current signal of 4–20 mA is converted to a voltage signal (commonly in the range 1–5 V) with a simple series resistor

MODULE 6

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.

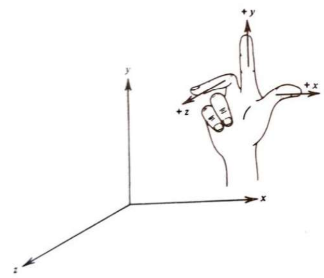


Figure 1-1 A right-hand coordinate system.

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.

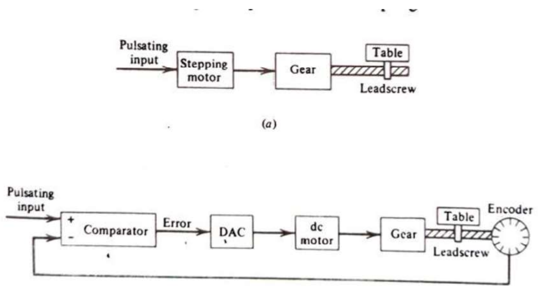
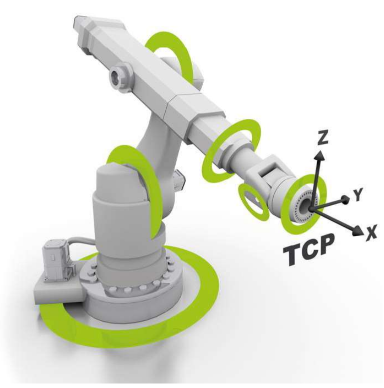


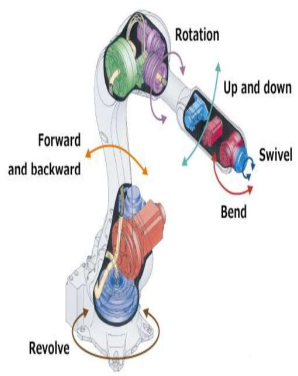
Figure 1-8 Open-loop (*a*) and closed-loop (*b*) digital control.

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.

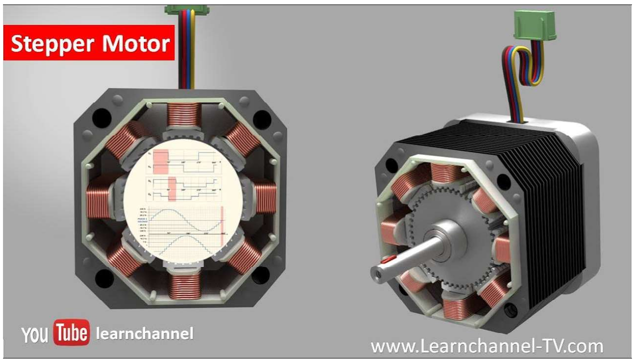
- Since there is no feedback from the slide position, the system accuracy is solely a function of the motor's ability to step through the exact number of steps which is provided at its input.
- The closed-loop control measures the actual position and velocity of the axis and compares them with the desired 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

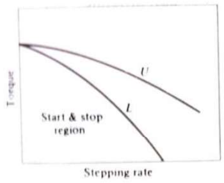
- Hydraulic systems can range in size up to hundreds of horse powers.
- They are well suited for large robots and NCC machine tools where power requirements are high.
- The cost of a hydraulic drive is not proportional to the power required, and, thus, they are expensive for small- to medium- Sized robots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

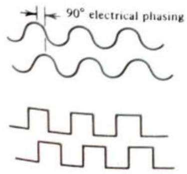


Figure 4-7 (*a*) Phase-shifted output produced by a two-channel encoder; (*b*) square-wave outputs are achieved by applying a Schmitt-trigger shaper.

- 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

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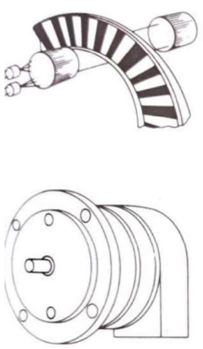


Figure 4-6 Incremental encoder with two-channel output.

- 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.

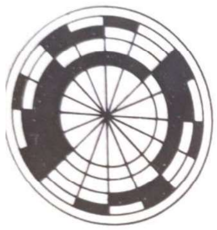


Figure 4-8 Binary code disk of absolute encoder.

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

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

The rotor outputs consist of two components

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

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

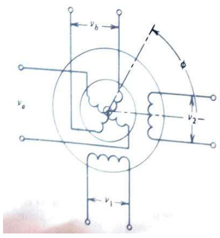
Substituting Eqs. (4-19) into Eqs. (4-20) yields

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

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

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

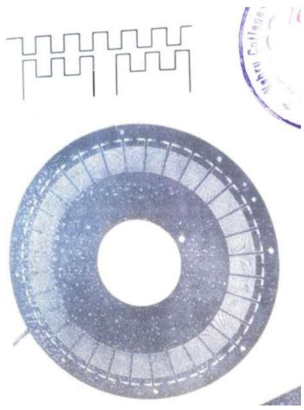


- In NC applications only one of the rotor windings is used, and it produces the feedback signal Va .
- The phase angle, which is contained in the feedback signal, depends on the angular position of the rotor shaft.
- Note that if the rotor is rotated 90°, for example, the phase shift of the rotor winding 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, (*b*) stator of rotary inductosyn, (*c*) stator (scale) and rotor (slider) of linear inductosyn. (*Courtesy of Far*... *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

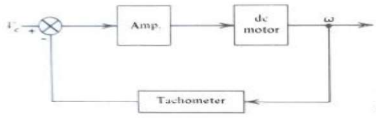


Figure 4-11 Typical machine drive un...

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.

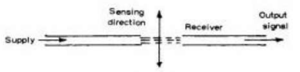


FIGURE 1

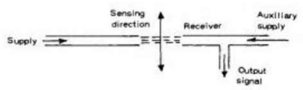
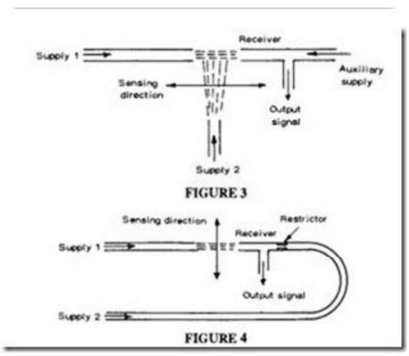


FIGURE 2



- 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.

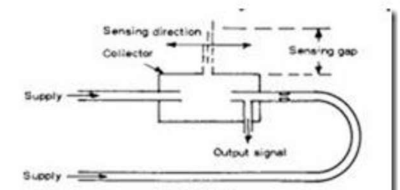


FIGURE 5

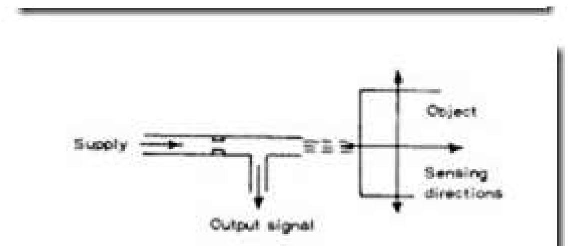
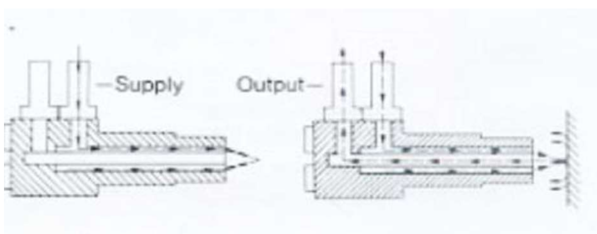


FIGURE 6

- 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.

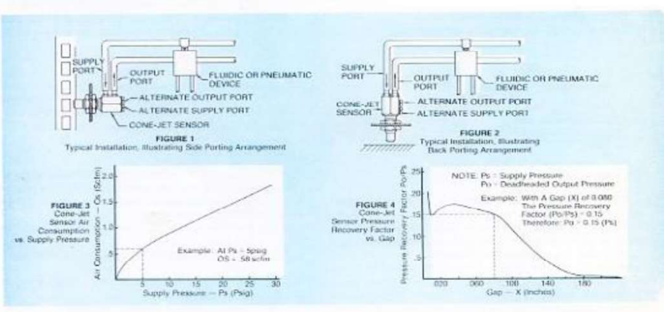
Cone-Jet Proximity Sensor



- 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.

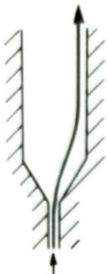
Sequencing Operation

- 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 .

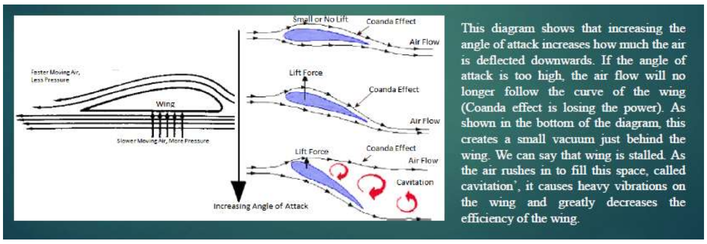
Coanda Effect

- 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.



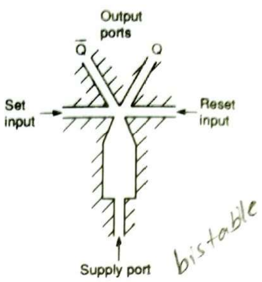
(a) The Coanda effect

- 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.
- lt 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.

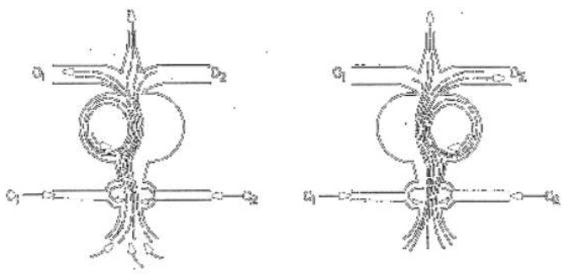
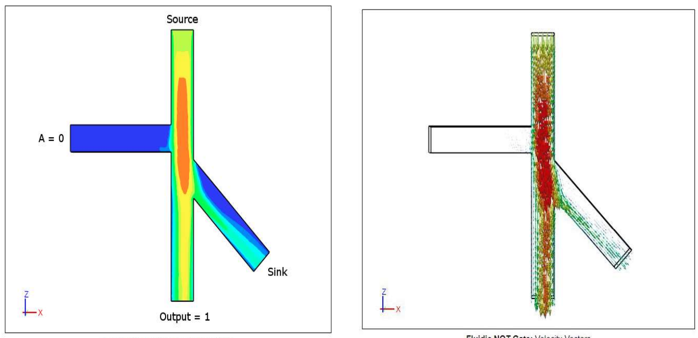


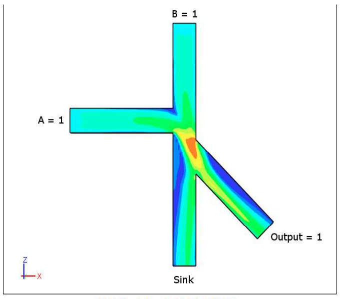
Fig.- 1 Fluidic amplifier, showing flow in both states. Ref: U.S. Patent #4,000,757.

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

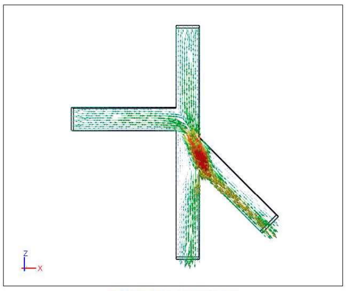


Fluidic NOT Gate: Velocity Magnitude

Fluidic NOT Gate: Velocity Vectors

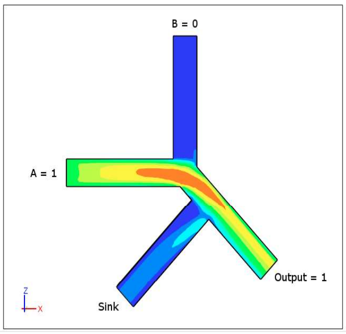


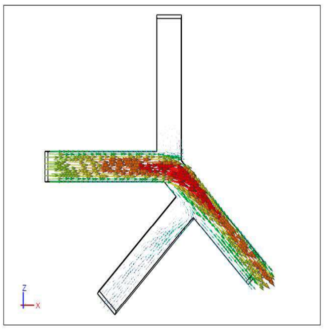
CFD Simulation of a Fluidic AND Gate


Fluidic AND Gate: Velocity Vectors

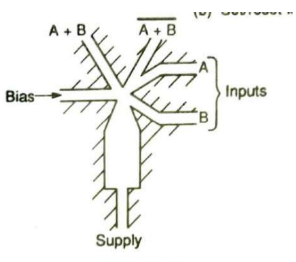
- A small bias pressure Keeps the signal on the right-hand wall, which causes it to exit via the right-hand port. If signal A or B is applied (at higher pressure than the bias) the flow switches over to the (A+ B) output.
- When both A and B signals are removed, the bias pressure switches the flow back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

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





OR/NOR gate



(c) OR/NOR gate

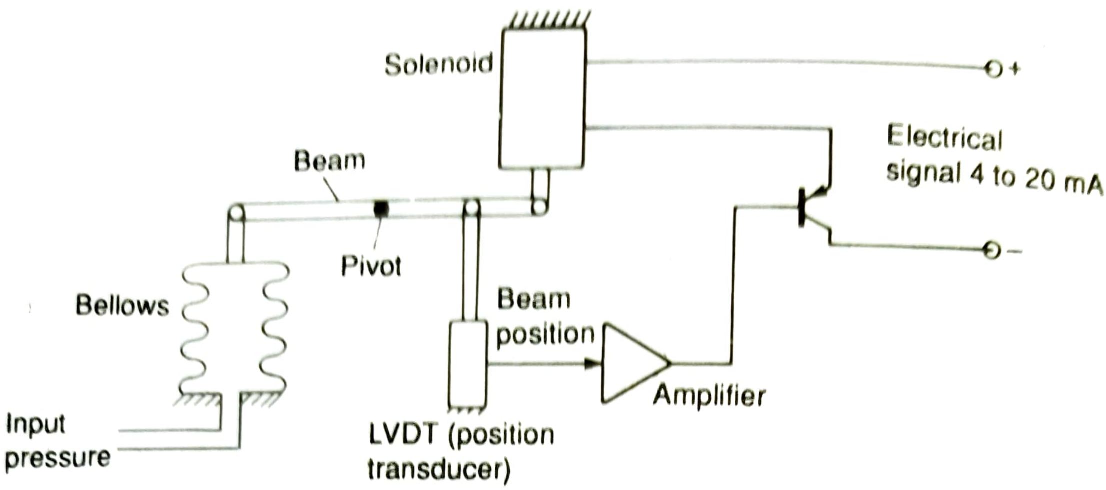


Figure 7.26 Pressure to current (P–I) converter

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 used to control a sequence (eg, feed a component, wait five seconds, feed next component). A time delay valve is

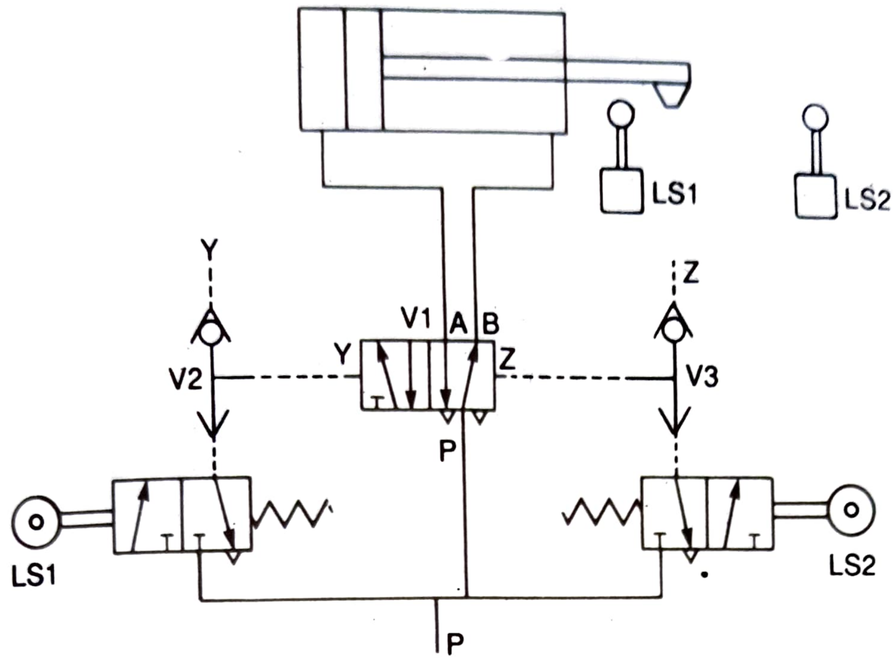


Figure 7.27 A sequencing example; the cylinder oscillates between LS1 and LS2

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

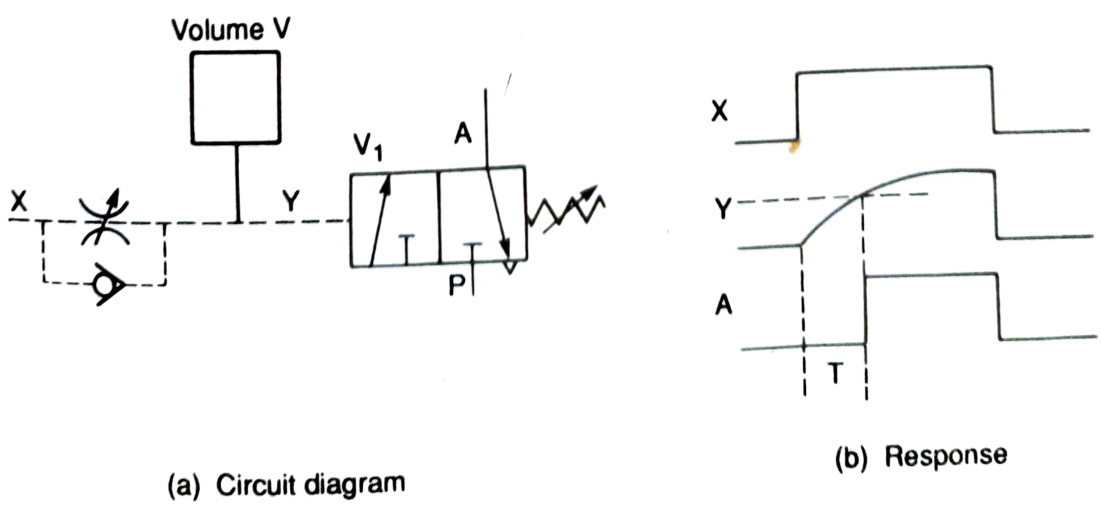


Figure 7.28 The time delay (see also Figure 4.28 for construction)

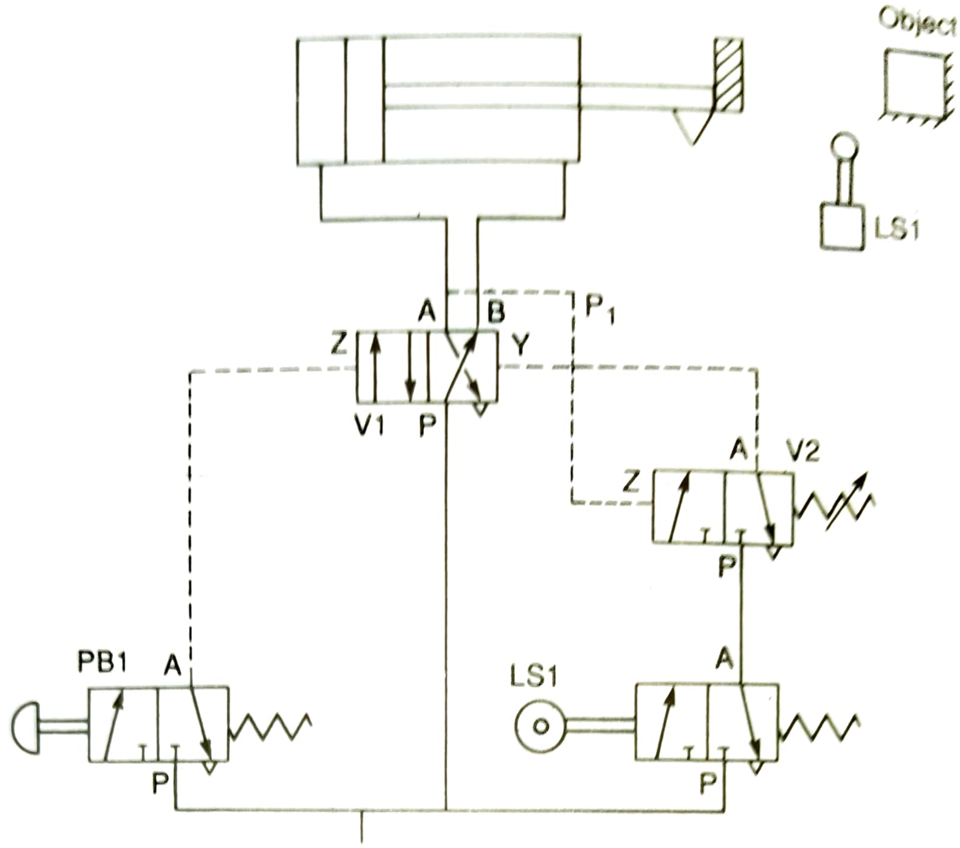


Figure 7.29 Sequencing valve application

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 object present, the jet produces a pressure rise at signal output X.

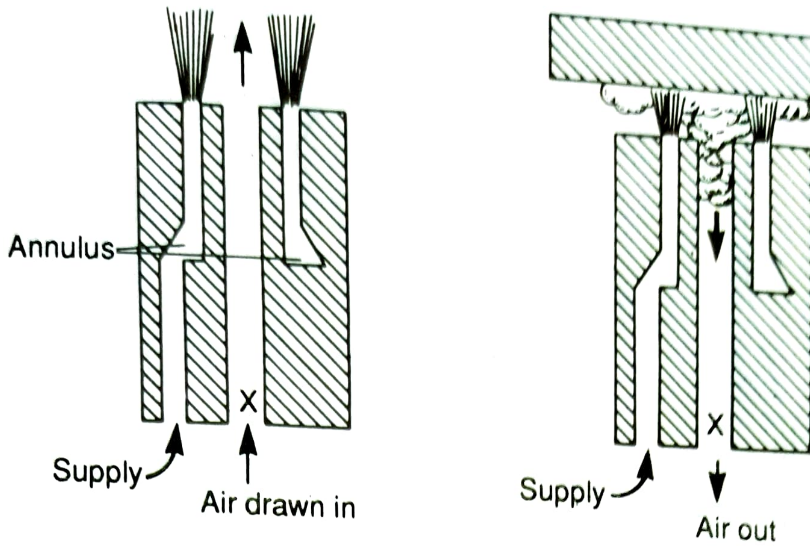


Figure 7.30 Reflex promixity switch

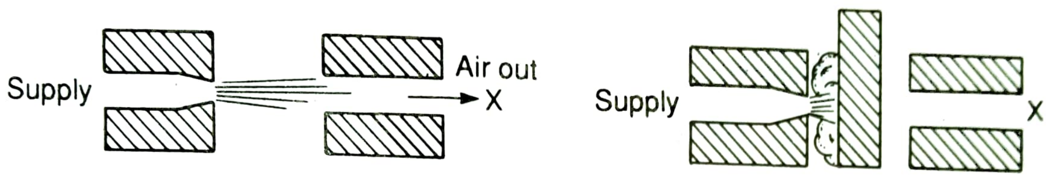


Figure 7.31 Interruptible jet limit switch

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 signal on the right-hand wall, which causes it to exit via

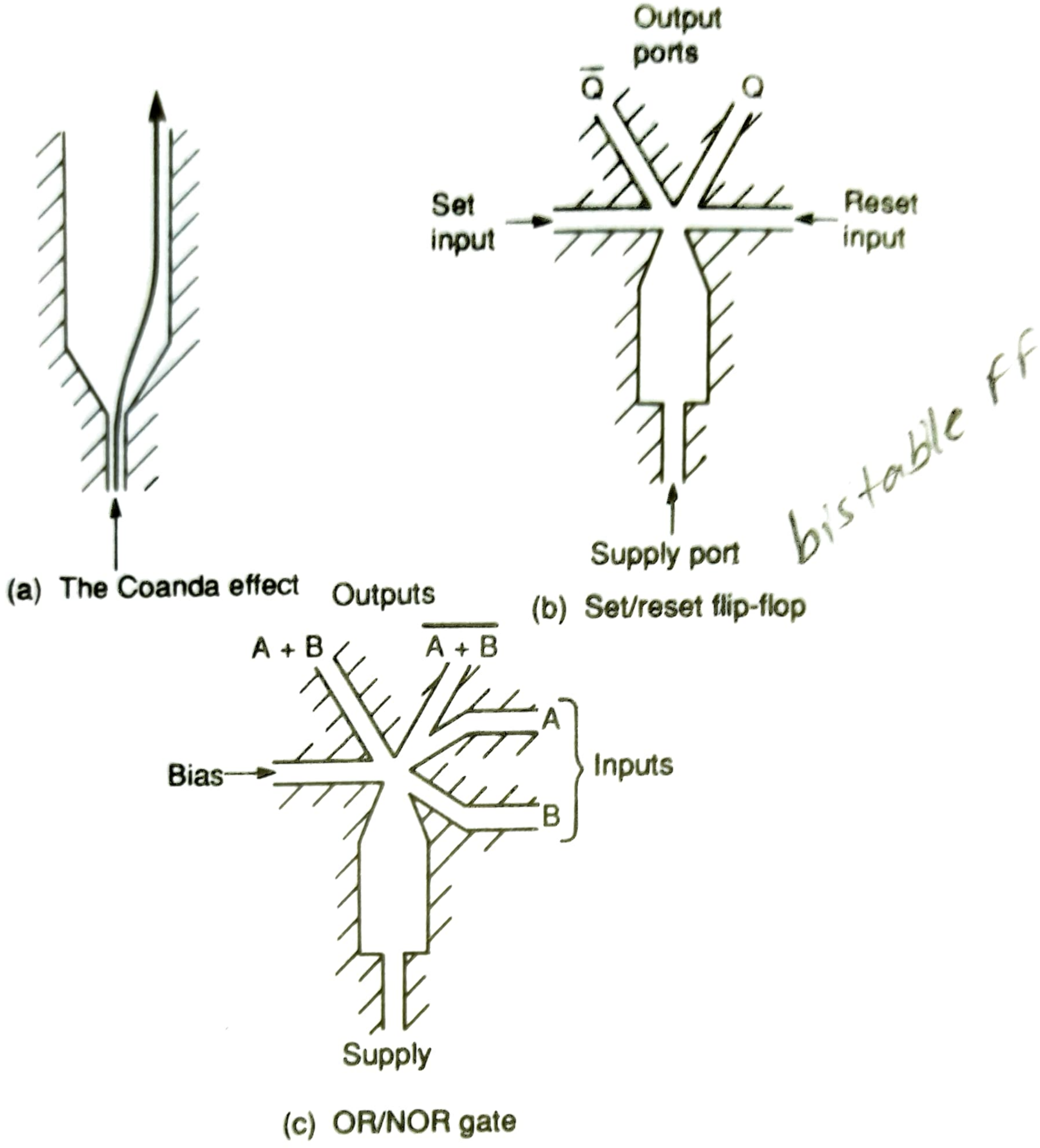


Figure 7.32 Fluidic logic

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):

$$\omega = \alpha K_a K_m V_c - \frac{\alpha R K_m T_s}{K_t} \tag{4-30}$$

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 their initial state is $Q_a = Q_b = Q_c = 0$. The first input pulse triggers the FF_a and

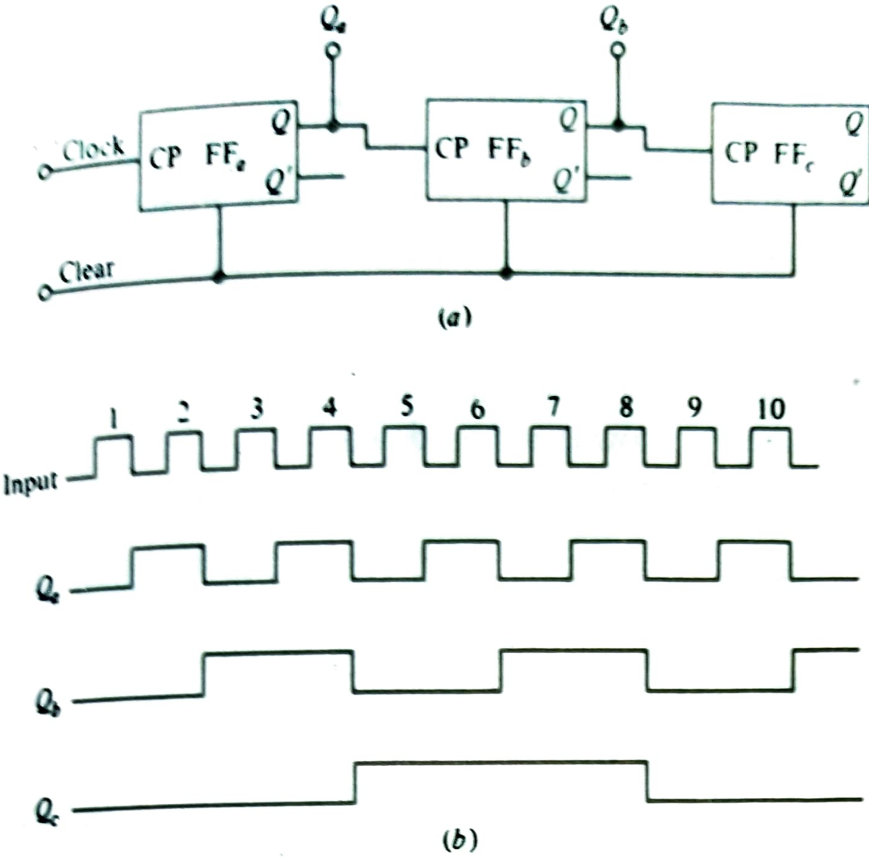


Figure 4-12 A 3-bit binary counter. (*a*) Logic diagram, (*b*) waveforms.

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
1	1	1	7
0	0	0	8

MRT 281:INTRODUCTION TO SENSORS AND ACTUATORS

Coating Technologies

Magnetic Materials Market and Applications

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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.

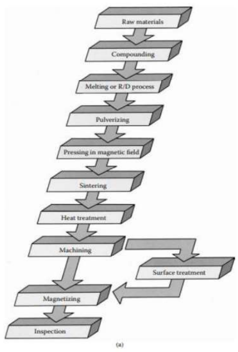

FIGURE 1.3
Rare-earth magnet manufacturing process: (a) sintered-based. (From Hitachi Metals Ltd., Hitachi Rare-Earth Magnets, 1999. With permission.)

- 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

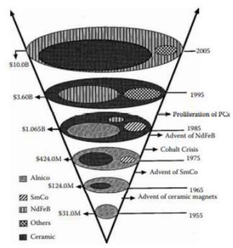

FIGURE 1.4
Growth of the PM market. (From Rashidi, S., NdFeB Opening Remarks, NdFeB '99 Conference, San Francisco April 12–14, 1999, p. 3. With permission.)

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

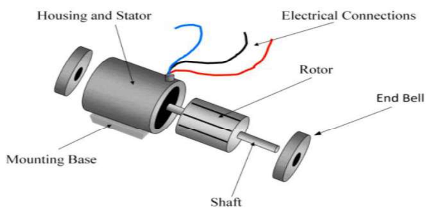
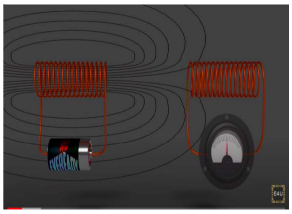


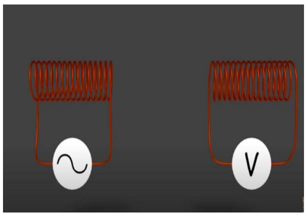
Fig.1: Motor Stator and Rotor

- 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.

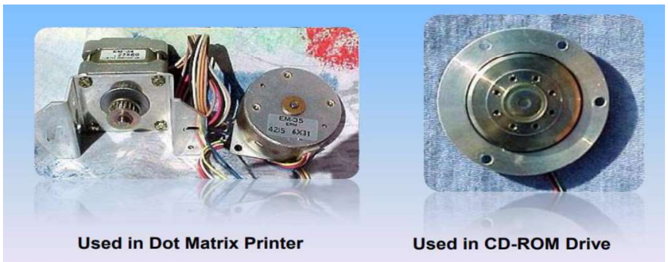
Working Principle

- 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



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**

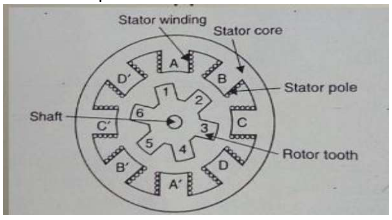
Application

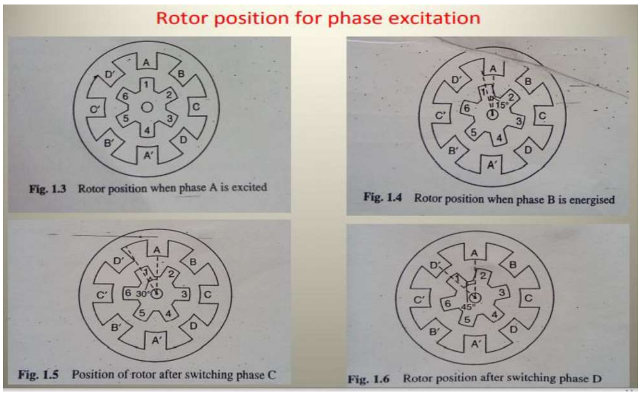
Application of stepper motor in diverse areas ranging from a small wrist watch to artificial satellites.

- 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

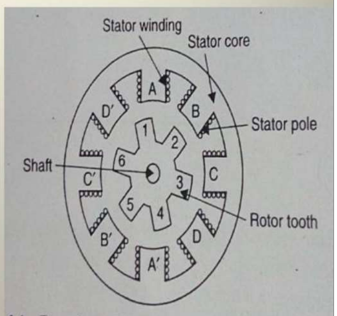
M = the number of stator phase

N= the number of rotor phase

In the present case M=4,Nr=6

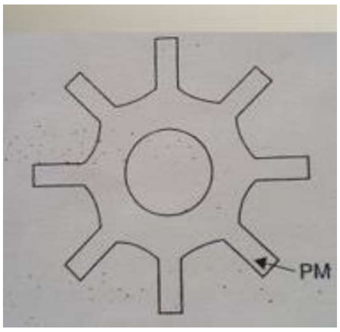
Φ=360/4x6 degree

Φ=15 degree



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

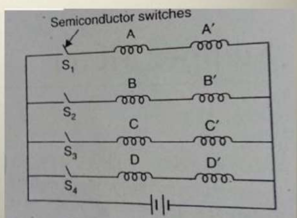
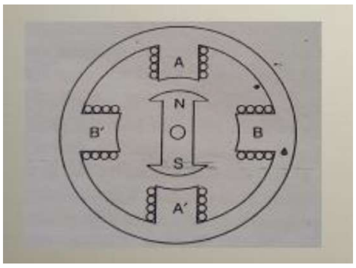


Fig. 1.2 Switching circuit

- 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/

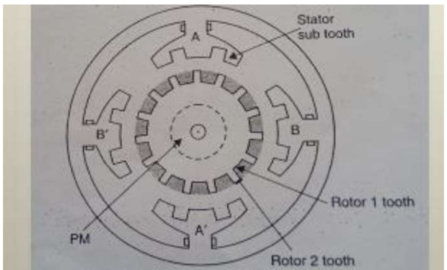


Fig. 1.23 Two-phase, four-pole HSM

Hybrid stepper motor