Mechatronics
Prof. Pushparaj Mani Pathak
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture - 12
Hydraulic and Pneumatic Actuators

I welcome you all to this lecture on Mechatronics. Today, we are going to see the Hydraulic and Pneumatic Actuators. You see any actuator in a mechatronics system works when the actuator receives a control action from the microprocessor or microcontroller whatever is being used.

So, that control action has to be converted into, some movable action. And that could be done by either of the actuators. And, today we are going to discuss hydraulic and pneumatic actuators.

So, as I said actuators are elements of the control system, responsible for transforming the output of your microprocessor or microcontroller into the control system, or control system into a control action on a machine or device.

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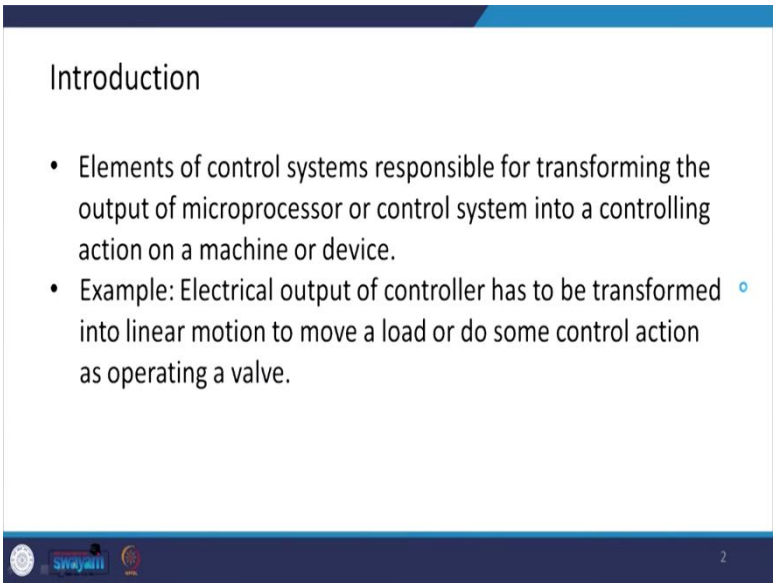

For example, I can take the electrical output of a controller has to be transformed into say linear motion to move a load, or to do some control action say operating of a certain valve of the hydraulic system or say some valve of the pneumatic system. So, this is where these

actuators are used. Now, before we proceed let us try to understand the characteristics of pneumatic and hydraulic signals.

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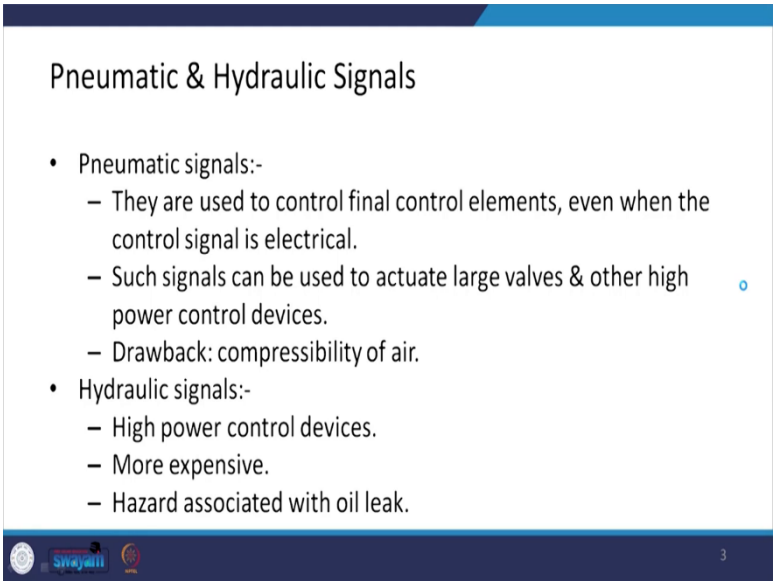

The pneumatic devices used air as the medium. So, they are used to control final elements even when the control signal is electrical.

So, although the control signal is electrical which is coming from the microprocessor or microcontroller, the final control element could be the pneumatic signal. And, these signals could be used to actuate the large valve and other high-power control devices. But, the drawback of the pneumatic signals is that the air which is being used as the medium is compressible. So, the compressibility of air is a problem.

Now, coming to the hydraulic signals these are used for the high power control devices, as we know that hydraulic signals are powerful. But, these devices come with many of the other peripheral things. So, because of that, they are more expensive and these hydraulic signals are achieved by devices that used the oil.

So, there are hazards associated with the oil leak. Now, let us lo at the difference between pneumatic and hydraulics. As we know that pneumatics used air as the working fluid whereas, in the case of hydraulics, we use the oil or a mixture of water-oil emulsion is used as the working fluid.

So, the fluid power denotes the use of pressurized fluid to drive, the linear or rotary actuators. And, this subject can be broadly divided into two fields pneumatic and hydraulics as I said in the case of pneumatic the working fluid is compressed air.

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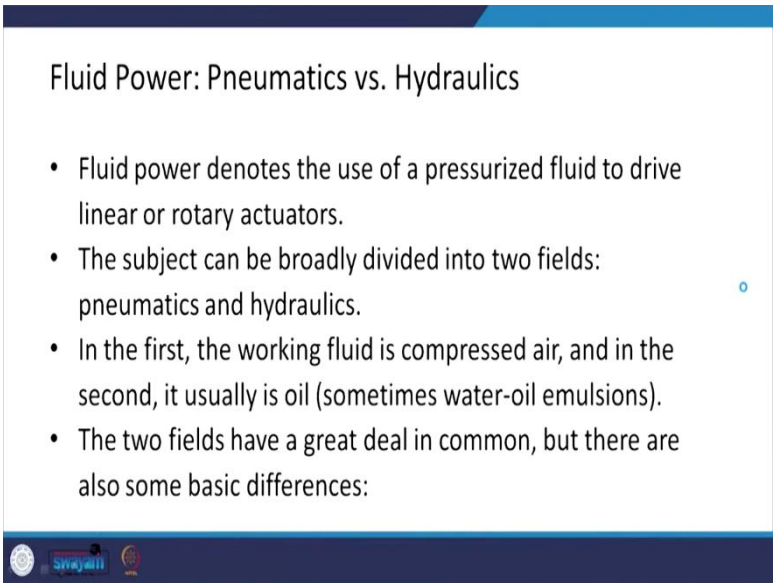

And, in the case of hydraulics, it is an oil or it is a water-oil emulsion. And, the two fields have a great deal in common, but there are also some basic differences between them.

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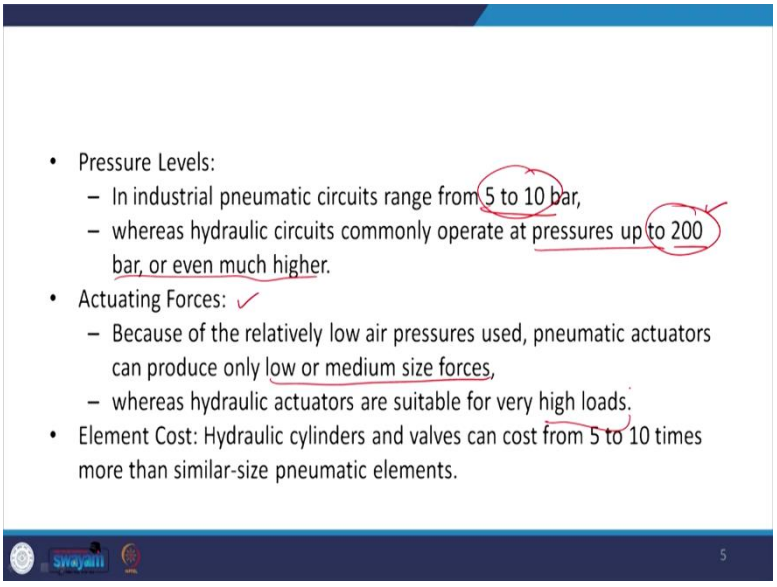

Let us see what are the differences between the two that are hydraulic and pneumatic systems. So, first of all, let us differentiate at the pressure level. In an industrial pneumatic

circuit, the pressure ranges from 5 bar to 10 bar. Whereas, in hydraulic circuit commonly used pressure is up to say 200 bar or even much higher.

So, you can see the difference. The pneumatic devices are the lower pressure devices whereas, hydraulic devices are the higher pressure devices. Now, actuating forces, because of relatively low air pressure used pneumatic actuators can produce only low or medium-sized forces, whereas hydraulic actuators are used for very high load.

And, if we lo at the cost wise how do they differ. So, the hydraulic cylinders and valves can cost you say 5 to 10 times more than the similar type of pneumatic elements. Now, let us compare the transmission line. Why transmission line? Because we need to transfer this compressed air or your liquid through the hydraulic devices.

So, hydraulic transmission lines are usually made of metal tubing needed to withstand the high working pressure and to avoid leaks. In pneumatic, we use flexible plastic tubing is used, and the fitting can be usually be done by the hands.

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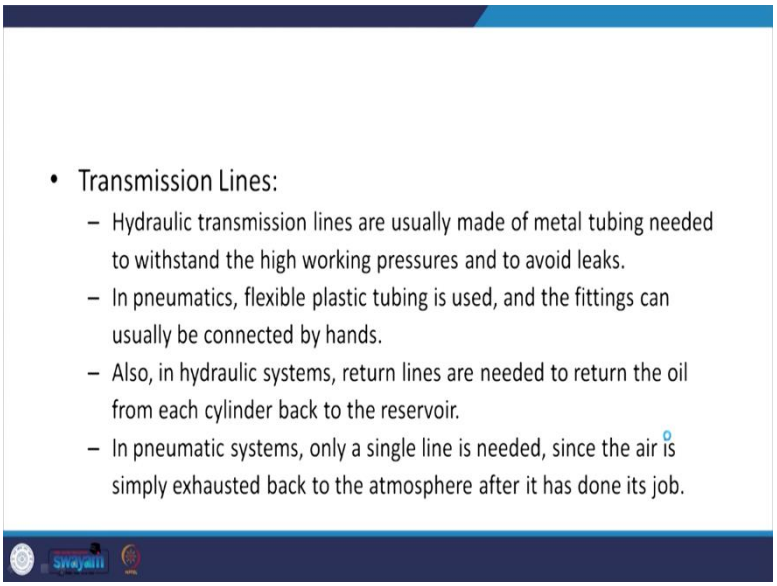

And you see in the hydraulic system the working fluid is costly. So, unlike the pneumatic system, where we can allow the air to escape to the atmosphere, in the hydraulic system we cannot allow the oil to escape into the atmosphere. So, we need the return line to return the oil from each cylinder back into the reservoir.

Then, about speed control, because of the compressibility of air, it is difficult to control the speed of pneumatic cylinders or motors accurately. So, there is a speed control problem with the pneumatic devices, because of the compressibility of the air.

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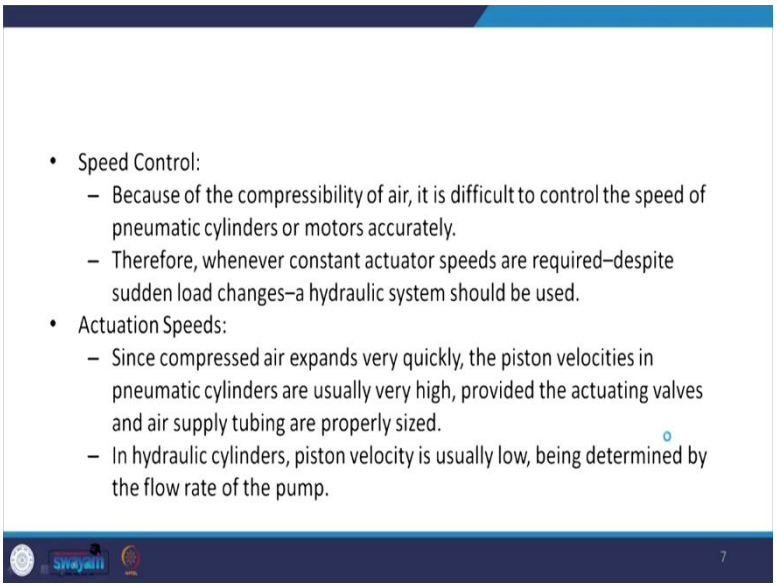

So, whenever constant actuator is speed is required, despite certain load changes we go for the hydraulic system, fine. What about actuation speed? Since compressed air expands very quickly, the piston velocities in the pneumatic cylinder are usually very high and they provide the actuating valves and air supply tubing are if they are properly sized and so, they do it quickly. Whereas in the case of hydraulic cylinder piston velocity is usually low being determined by the flow rate of the pump.

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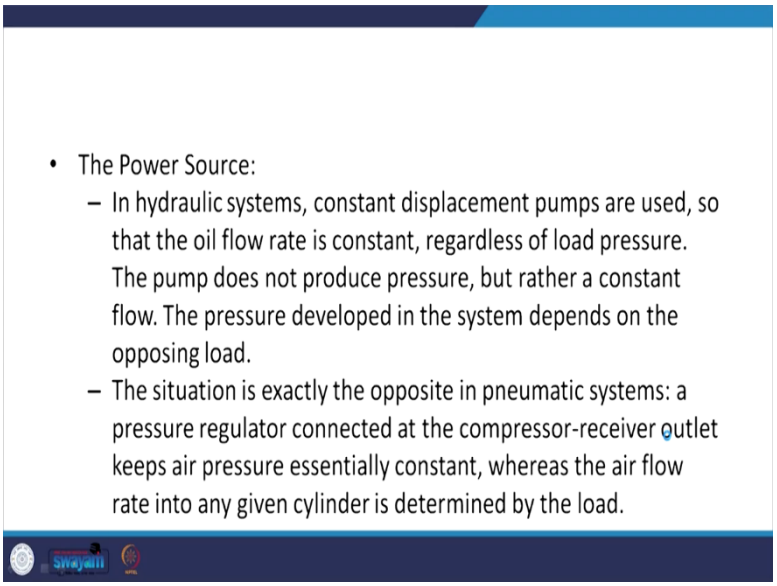

Coming to the power source in the hydraulic system, we use constant displacement. So, that the oil flow rate is constant regardless of the load pressure. The pump does not produce pressure, but rather a constant flow. The pressure developed in the system depends on the opposing load.

Whereas, the situation is exactly the opposite in the case of a pneumatic system, in the case the pneumatic system a pressure regulator connected at the compressor receiver outlet keeps the air pressure essentially constant, whereas the airflow rate into the given cylinder is determined by the load. So, in the case of the pneumatic one, the airflow rate is determined by the load whereas, in the case of hydraulic one the pressure developed in the system is determined by the load.

Now, let us lo at what are the various components of the hydraulic and pneumatic system because we are going to use these as an actuating device in our mechatronic system. So, what are the essential components? So, as I said there are many things common between hydraulic and pneumatic devices, alright.

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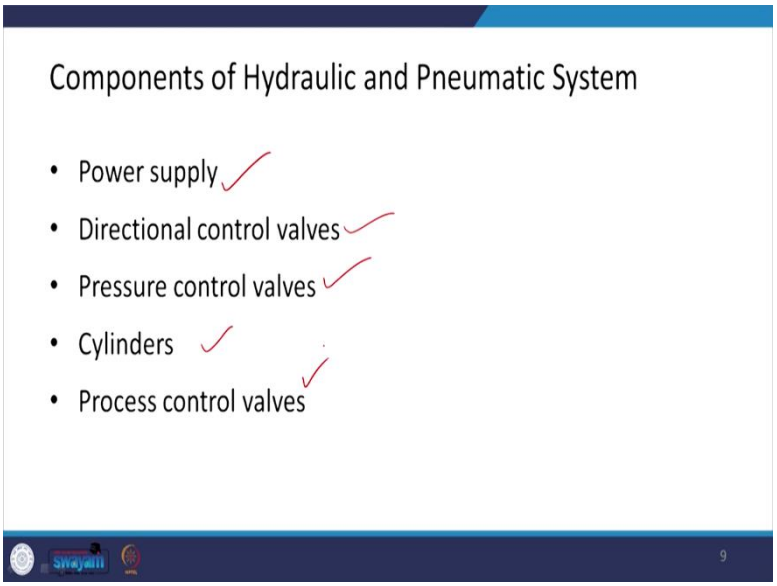

So, these components could be say the power supply, directional control valves, pressure control valves, cylinders, and the process control valve. So, these are the various components.

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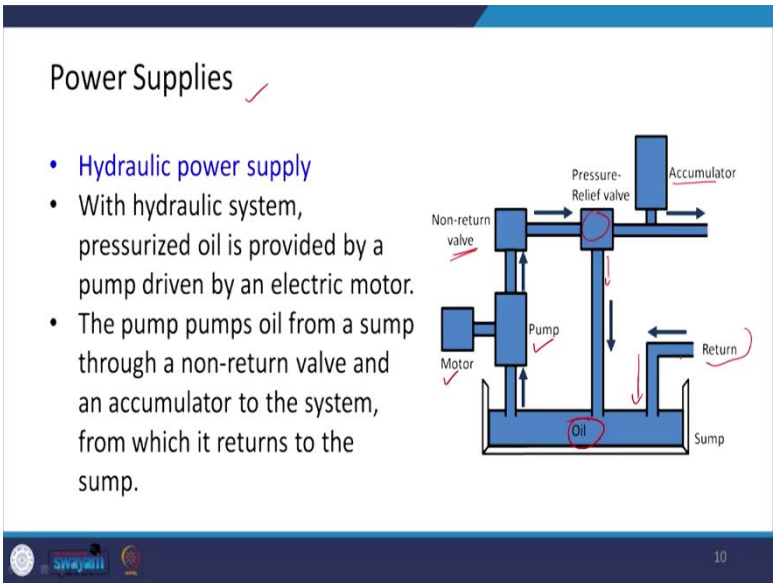

Let us look at it one by one. So, first of all, we will be looking at the hydraulic power supply. Now, in the hydraulic power supply as I said we are using oil. So, there is a sump where oil is there now, this oil is pumped with the help of a pump and this pump is actuated by a motor. Now, oil from the pump goes to a non-return valve. So, that oil does not come

back to the sump from this side. And, then it goes to a pressure release valve over here, in order to release the excess of pressure, and then it goes to the accumulator.

And whatever oil is remaining or returning, that returned is through the returned side and that oil can come back to the sump and, then this cycle can be repeated. In the pressure release valve also the oil is brought back to the oil sump. So, here in the hydraulic system, the pressurized oil is provided by the pump driven by the electric motor. The pump oil from the sump through a non-return valve and is sent to the accumulator to the system from which it returns the sump.

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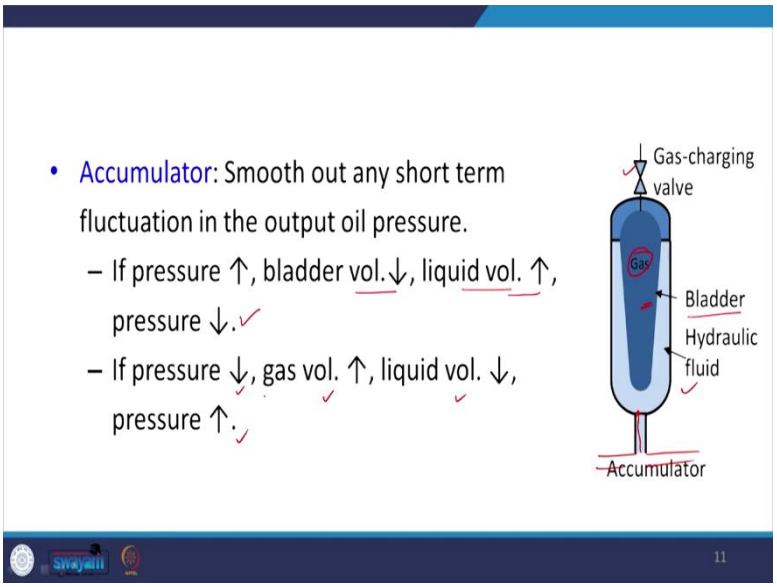

Now, what is this accumulator? So, this accumulator is a device to smooth out short-term fluctuation in the output oil pressure, and how this is done? So, this device has got a there is a bladder, on which gas is there. And, there is a gas charging valve through with this gas can be charged and there is a hydraulic fluid over here.

Now, what happens if the pressure here increases? So, if the pressure increases what will happen this bladder will shrink. So, the bladder volume will decrease, and if the bladder volume decreases, what will happen? The liquid will be occupying more and more space. So, the liquid volume will be increasing and this will return your fall in the pressure; this will return your fall in the pressure. And, if there is a reverse situation that is if your pressure is decreasing alright, then what will happen if pressure is decreasing? Your bladder will be expanding more.

So, your gas volume will be increasing and, if your gas volume is increasing, then naturally the liquid volume is going to decrease and if the liquid volume is going to decrease your pressure is going to increase. So, this way your accumulator is smooth out the short-term fluctuation in the output oil pressure.

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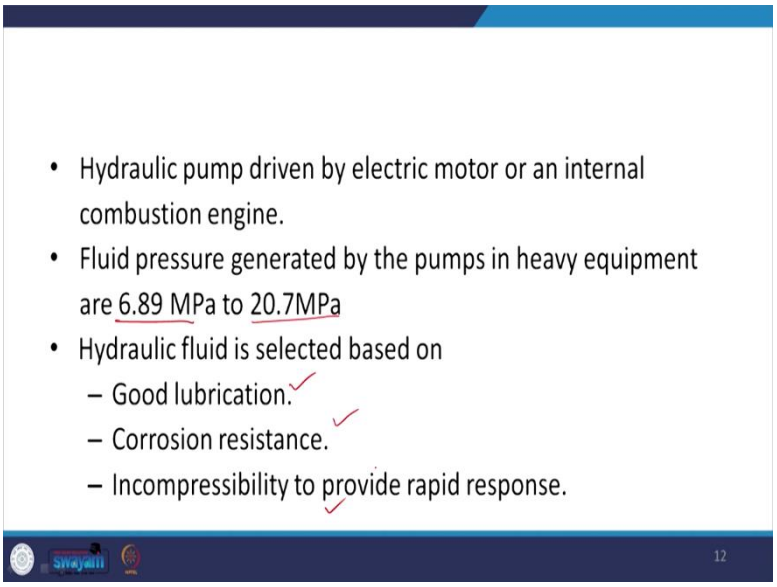

So, hydraulic pumps are driven by an electric motor or internal combustion engine that could be there. And, fluid pressure generated by the pump in heavy equipment is said from 6.89 mega Pascal to around 20.7 mega Pascal.

And, when we are selecting the hydraulic fluid for our mechatronic system, the selection criteria have to be based on the lubrication property that is it should be good lubricate, it should be corrosive resistance, it should not corrode to the component of the hydraulic actuation system and it should be incompressible. So, that it can provide rapid response, unlike the pneumatic system where we use the air which is compressible.

Most hydraulic pumps are actuated by the positive displacement devices, that is they deliver a fixed volume of liquid in each cycle. And, there are three main types of pumps are used these are the gear pump, vane pump, and piston pumps. So, in the gear pump, there are two gears.

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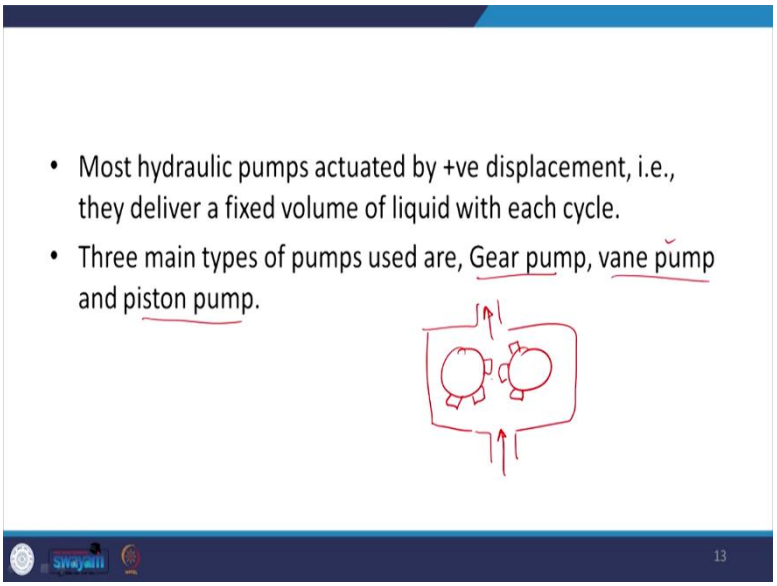

So, the two gears are there like this and these gears are in mesh. So, something like this they are there this device is there in a casing. And you have the input from here, and you have the output from here and it compresses and displaces the liquid. Similarly, the vane pump has got vanes, which displace the liquid and likewise with the piston pump.

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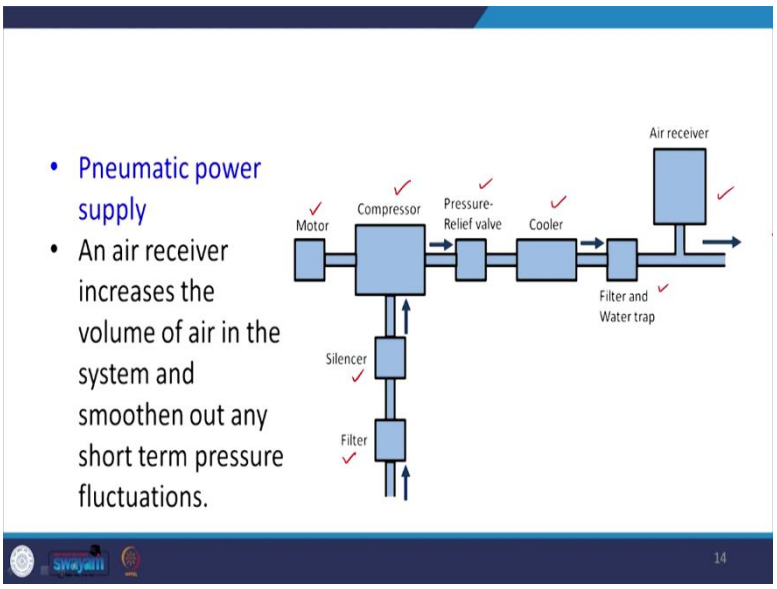

Now, let us lo at the pneumatic power supply. So, the pneumatic power supplies are something like this. So, you have to take in the air. So, there is a filter to remove the dirt

and other thing and there is a silencer being used in order to remove the noise, and then there is a compressor to compress it.

So, you have a motor to drive the compressor. So, if there is excess pressure you have the pressure release valve from, where you can control the pressure. When this air is compressed in the compressor, it gets heated. So, you need a cooler to cool down that air, and then the filter. When moisture traps in the air it gets condensed. So, that moisture can be removed in the filter and water trap. And, then it goes to the air receiver, and then you have a supply.

So, this is our pneumatic power supply. And, this air receiver increases the volume of air in the system and smoothens out any short-term pressure fluctuations.

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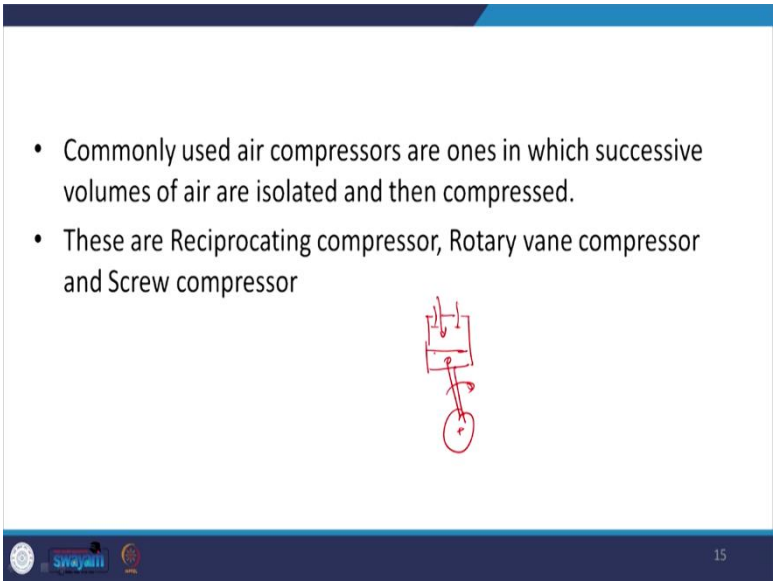

Commonly used air compressors are one in which successive volumes of air are isolated and then compressed. These are the reciprocating compressor, rotary vane compressor, and screw compressor.

And the reciprocating compressor principle is again very simple, as you can see that we have some cylinder and piston arrangements. And you have the inlet port and you have the exhaust port, and air comes in, and then it is compressed by the piston and then it is delivered.

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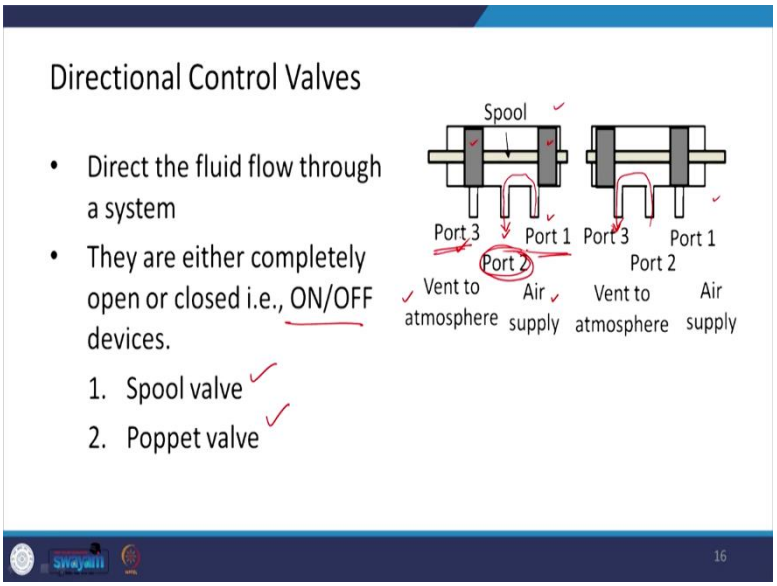

So, the same principle is used in your IC engines. Then, the other element is the directional control valves. So, as the name indicates they direct the fluid flow through a system, and they are either completely open or closed or what we call the ON-OFF devices. So, these are of two types the spool valve and the poppet valve.

So, let us see the spool valve. So, this figure illustrates the spool valve so, here there are three ports port 1, port 2, port 3. So, through port 1 there is an air supply and through port 3 there is a vent to the atmosphere. And through port 2 the pressure is given to your device wherever you want to use it. So, this spool has got say these two pistons are there which constitute the spool and you have a soft.

So, in this condition, you see that this inlet valve is open and this supplied to the air is supplied to the device this way. And, in this configuration it is exhausted so, this goes from your device to the vent to the atmosphere. So, this way it is there.

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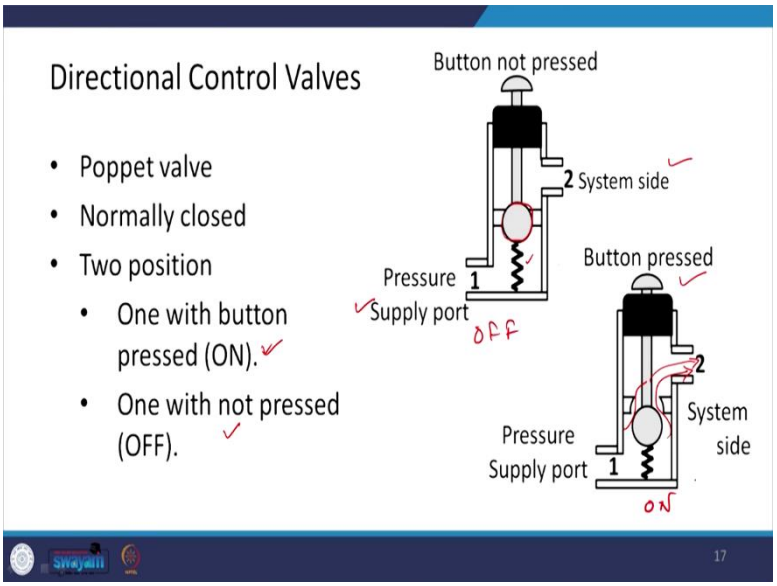

Now, poppet valves if we talk about poppet valves, they are normally closed. So, this is how the poppet valve configuration is so, you have this device here, there is a ball over here and you have a spring, this is the pressure supply port and this is the system side port. So, if the button is not pressed so, you can see that this is there in a closed position because this is spring. So, the spring keeps this valve closed position.

So, there are two positions here; one is with a button pressed that is ON. So, if you press the button then what will happen? This spring will be placed and the pressure supply port will be connected here to the system side. So, one with the button press that is ON position and one with not pressed this is the OFF position. So, this is your OFF position and this is your ON position.

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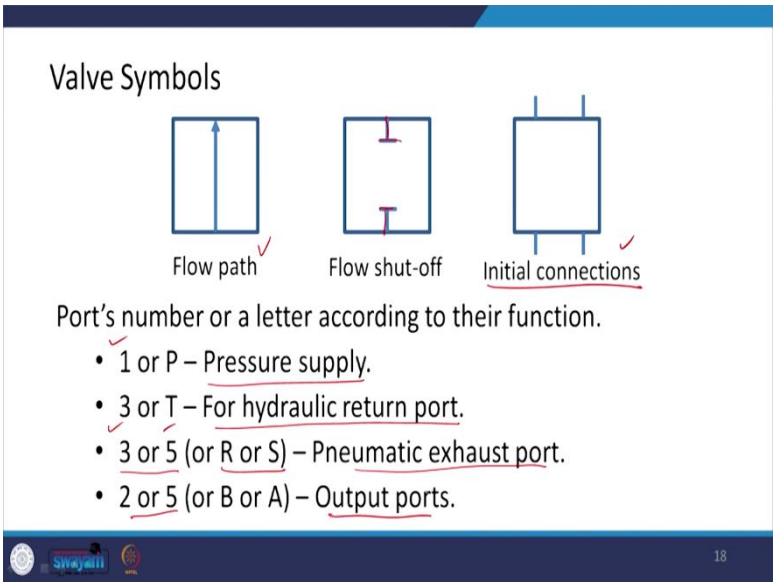

Now, in a circuit hydraulic circuit, there could be many types of valves being used. So, to represent the action, we use the valve symbols. And, these valve symbols say we in these valve symbols, we indicate the flow path like this and if the flow is shut off, then it is indicated like this. And, this configuration indicates the initial connections.

And, there is a standard port numbering or a letter according to their function say 1 or P is used for the pressure supply 3 or T is used for hydraulic return port. Say 3 or 5 or R or S is used for the pneumatic exhaust port, and 2 or 5 or B or A are used for the output port, as I have shown you over here. So, this 2 is used for the output, 1 is used for the input, and 3 is used for the exhaust; I hope it is clear.

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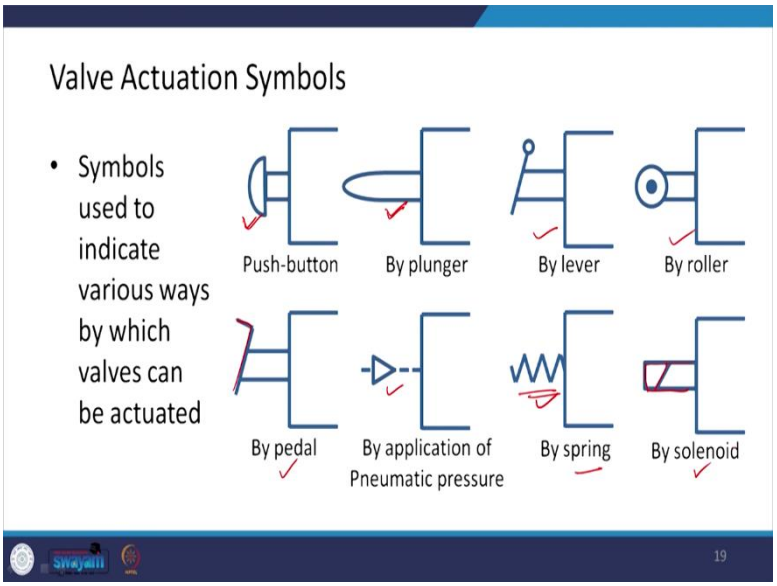

Now, there are various valve actuation symbols that are used. So, this is the symbol for the push button, this is the symbol for the plunger. So, here it looks like a button. So, if this symbol is there it means that the valve actuation is through the push button, this is valve actuation through the plunger, this is for using a lever, this is using a roller, this is by a pedal; a pedal shape is here.

And by application of pneumatic pressure, this is indicated. And, if your spring is here shown here, it means that it is actuated by a spring. And if it is shown like this, then it means that it is actuated by a solenoid. I will discuss solenoids when we will talk about the electrical actuation systems. Now, for the 2 by 2-way poppet valve actuation symbol, this is the 2 by 2 poppet valve which we have seen.

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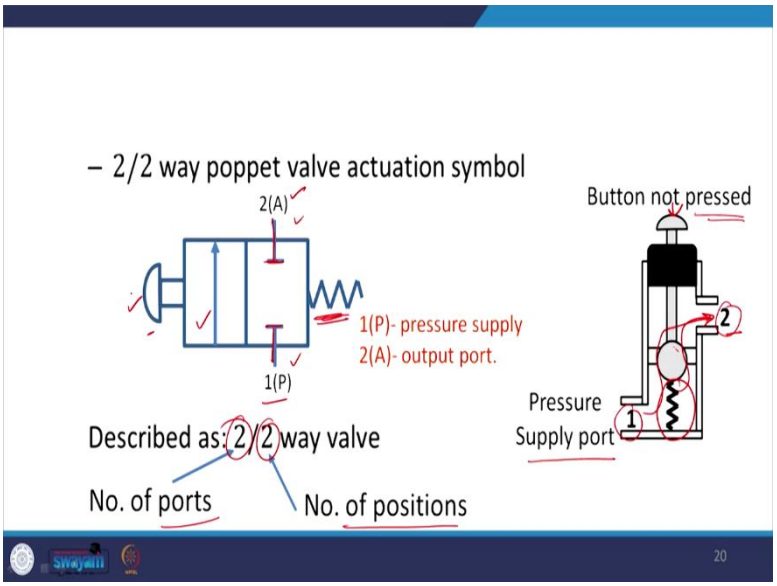

It is a pressure supply port and it has the here, port number 2 which is connected to the application side. And, you see that this valve has how many, it has how many ports? It has 2 ports. So, these are the 2 ports.

So, in the 2 by 2 symbols first symbol tells you the number of ports and the second symbol tells you the number of positions. So, what are the number of positions here? The first position is when there is communication between said inlet and outlet, and the second is when there is no communication. So, these are the OFF position been indicated. So, there is 2 positions number of position and there are 2 ports.

So, we have the inlet port and we have the application port, where that valve is communicating with the device. And you see with the help of this spring when this is spring is in action the valve is closed, that is why here towards the spring side we are seeing this symbol, and when we are pressing this button. So, on the button side if we are pressing there is a communication and liquid flows like this.

So, for that purpose this when there is a communication between 1 and 2 we are indicating it towards that button side. So, this is the nomenclature, which is used to indicate in your drawings. Now, let us look at the solenoid-operated spool valve.

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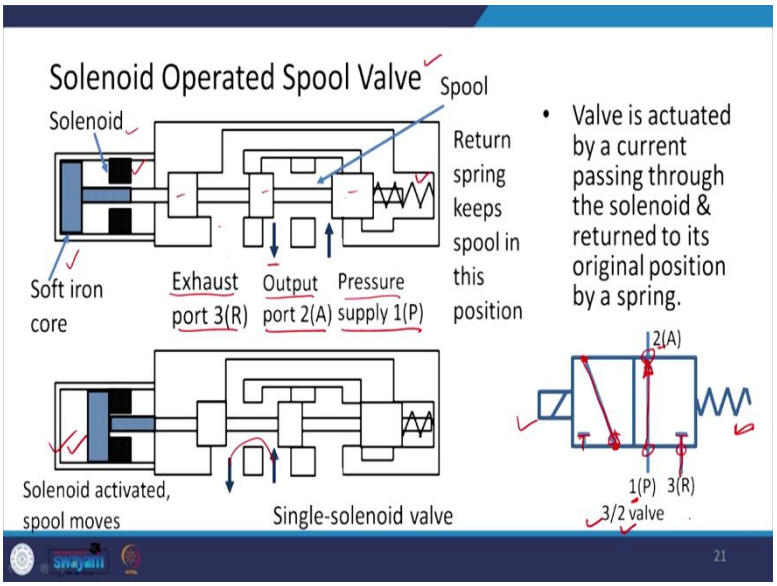

So, I have this spool valve this is the rod and these are the pistons and this is actuated by the solenoid over here. So, there is a soft iron core and you have a solenoid, I just said I will be talking about this solenoid in my electrical actuation devices lecture.

And, there is a return spring here to keep the spool in this position. So, in this position you have you see this is port 1 that is the pressure supply port; this is port 2 that is the output port and this is port 3 or the exhaust port. So, in this one in this device how many ports are there? 3 ports.

So, we have the 3 ports in the symbol, I am talking about 1, 2, and 3. These are the 3 ports. And, this is one operation where the pressure supply is communicating with the output port and the other one and this one is activated by a spring. So, when the spring is actuated there is communication between 1 and 2. So, we are seeing this thing and the third is closed third is not used. So, this is how it is seen.

Now, when you actuate this solenoid. So, what will happen? This iron core will move. So, in that due to this motion, this is the position, which will be getting and 2 port starts communicating with a port number 3 this way. So, you have the communication this way, I have explained this in my earlier slide also.

Now, this actuation has been done with the help of a solenoid. So, I have a symbol of solenoid over here, and in this one who is communicating with what? So, 2 is

communicating with 3. So, this is the 2 port and this is the 3 port. So, the 2 is communicating with 3, and 1 is closed so, 1 is over here. So, I hope with this you are able to understand, how we are representing this 3 port 2 position valve.

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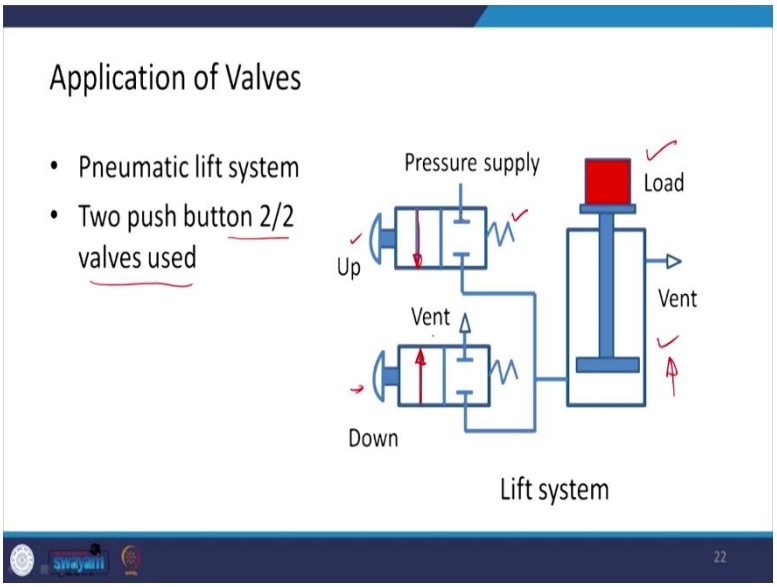

Then, there are these valves can have various applications such as a pneumatic lift system. And, in this pneumatic system, you could have a load here, and you could have a cylinder piston type of arrangement say over here, and we can use that two push 2 by 2 valve can be used.

So, with the help of spring in the spring these two valves are when your spring is acting, these two valves are not communicating. And when you push that button you are going to have the liquid flow are taking place here, and this will be going up.

And, when you are switching this button-down, then in this condition your liquid will be moving in the opposite direction. So, this is how this thing is going to work. Then, there are pilot-operated valves say force required to move the balls or a shuttle in a valve is often too large many times for manual or solenoid operation.

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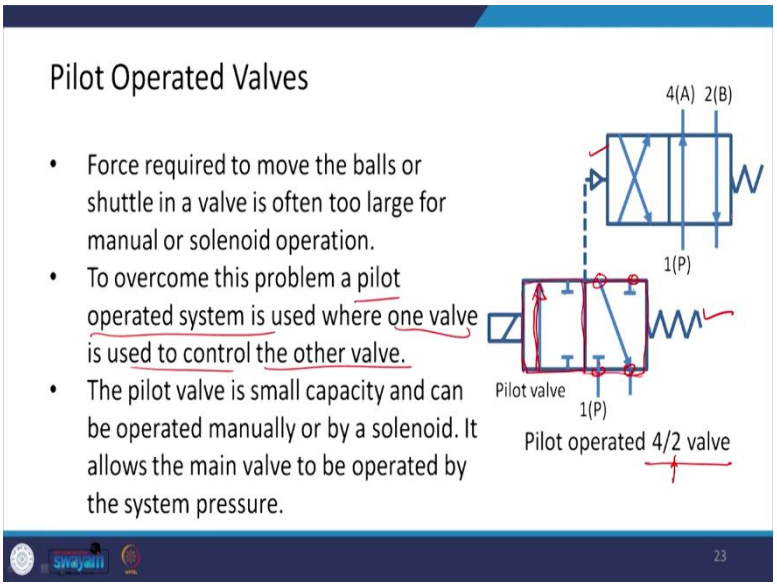

So, to operate a valve we require another valve. So, that thing can be done over here. So, to overcome this problem pilot operated system is used, where one valve is used to control the other valve. The pilot-operated valve is a small capacity valve and it can be operated manually or by a solenoid, and it allows the main valve to be operated by the system pressure. So, for example, in this figure, you can say that this is the pilot-operated 4 by 2 valve. There are 4 ports here and there are 2 positions. So, one is this position and the second one is another position. When spring is acting in this position, there is a communication between this and this port whereas, this and this port are closed. And, when you are applying a solenoid there is communication over here and the air is being supplied whereas, these and these are closed.

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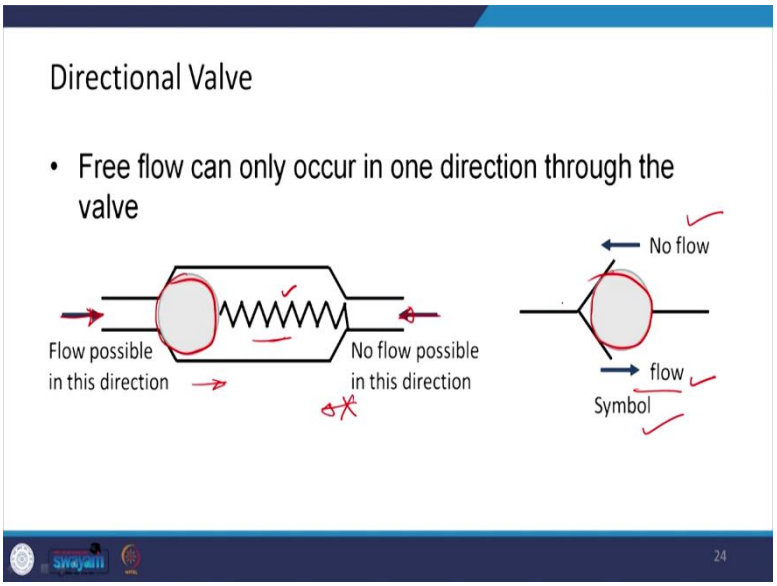

And this is the pneumatic signal which is going to your other valve.

Then, there are directional control valves and they allow free flow can occur in only one direction. For example, you see this arrangement here, the flow is possible in this direction. Because this ball is going to block any flow. And this ball is kept in this position with the help of this spring whereas; the flow is possible in this direction because, if the flow will be taking place this ball will be pressed, because of the pressure from the flow side. So, this direction flow is possible and this direction flow is not possible. This is represented in the symbolic form like this, this direction flow is there this direction flow is not there. And this is the symbol for representing your ball.

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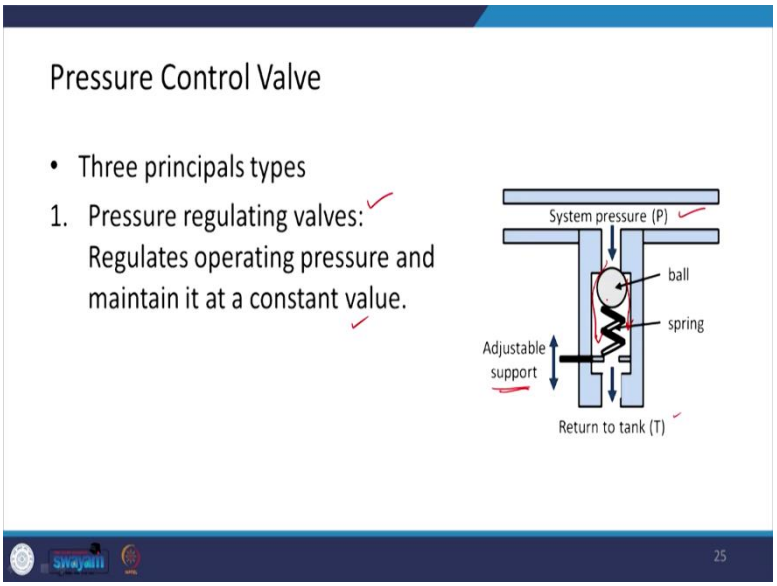

Then, there are pressure control valves that are used in these systems. There are three principal types are there, one is the pressure regulating valve. They regulate operating pressure and maintain a constant value. Here, the system consists of something like this, you have a system pressure here. If the pressure exceeds this ball is pressed and of course, whatever your working fluid is there that is released. The pressure at which it should be released can be done with the help of this adjustable support.

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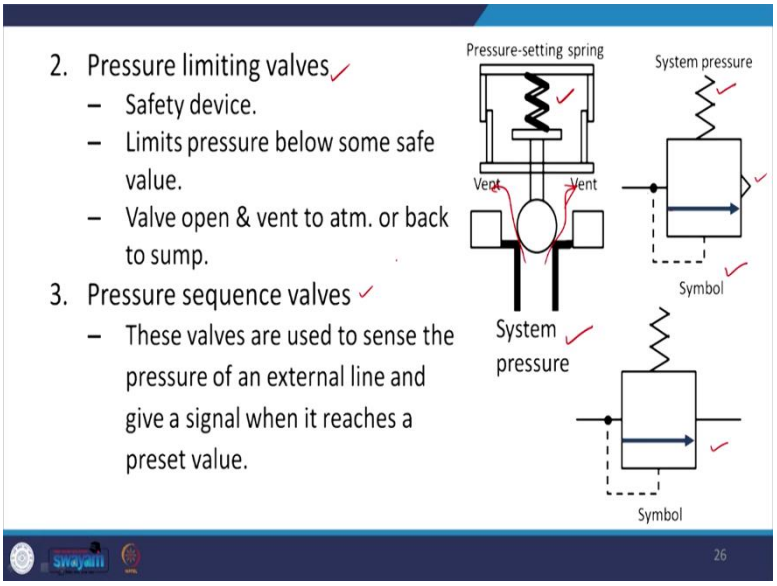

Then, we have the pressure limiting valve. As the name indicates, they are safety devices. They limit the pressure below some safe value, and the valve opens and vents to the atmosphere or back to the sump. So, here is the system pressure side, this ball is kept in this position with the help of this spring and so if there is excess pressure. Then, this is how it is vented. You can see the system pressure spring is there, this is the symbol there is a communication from this side to the vent side, this is your flow direction and this is your symbol for the vent. So, this is the condition when the venting is not there.

Next here is the pressure sequence valve. These valves can be used to sense the pressure of an external line and give a signal when it reaches the preset value.

Next, let us see cylinders. So, hydraulic and pneumatic cylinders are an example of linear actuators.

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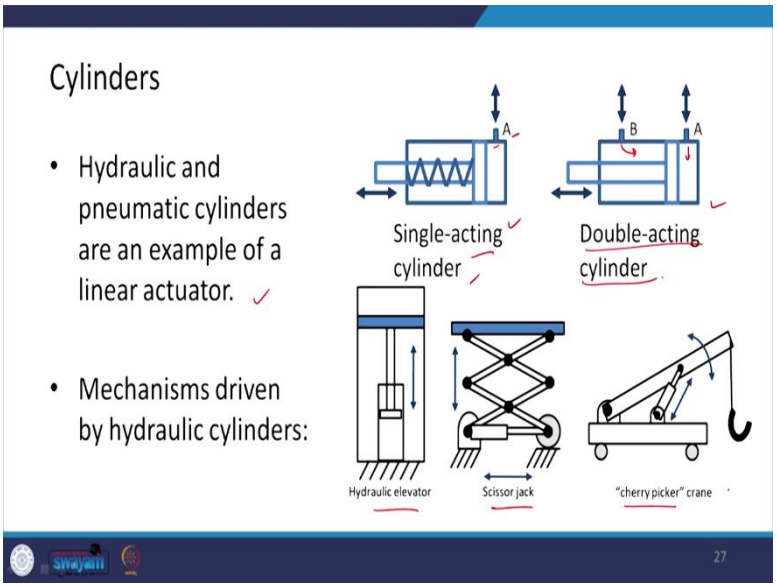

There are various mechanisms that could be driven by hydraulic cylinders. These cylinders could be either single-acting, or they could be double-acting.

Single-acting means, you have supplied from one side and in double-acting, you have supply from both sides of the piston. So, you could have supply from the B side, as well as supply from the A-side. So, this is what we call the double-acting cylinder and, if supplies are from only the A-side here, then this is called the single-acting cylinder. And, these are used in say hydraulic elevator or scissor jack, or cherry picker crane.

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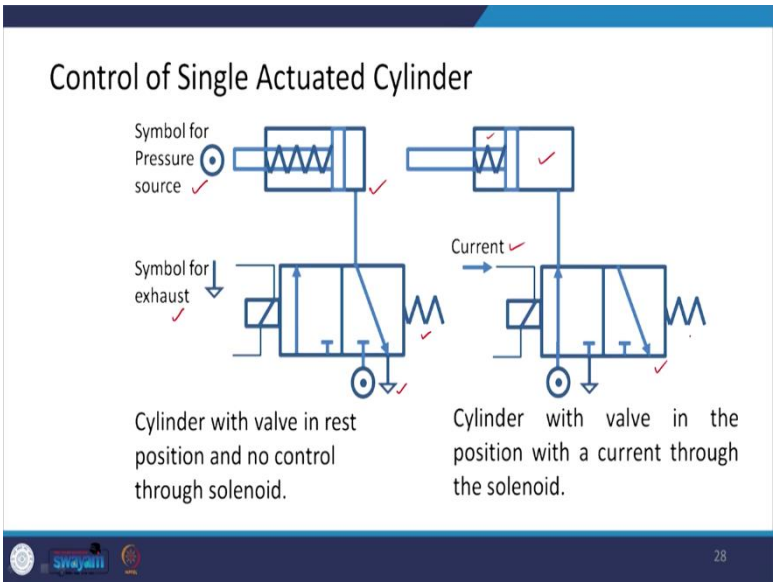

Control of single actuated cylinders; these are the two symbols that I am using the for pressure source and for the exhaust.

So, when your spring is acting in this condition, you have the exhaust being taking place and when your solenoid is acting you have the communication. Here, in this case, when we supply the current, the solenoid is acting and you have the pressure supply to this cylinder. The input takes place and when this is not there, then the spring acts and the exhaust takes place.

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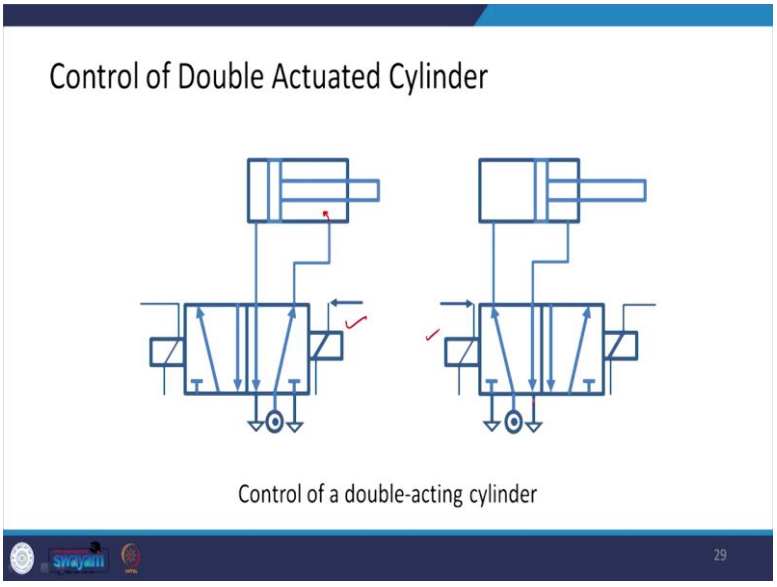

Then, we could have control for the double-acting cylinder also. So, in the case of a double-acting cylinder, when this solenoid is acting, you have the flow from this one, and exhaust takes place from here alright. And, when this is solenoid is acting in that case you have flowed from this side and exhaust takes from this side.

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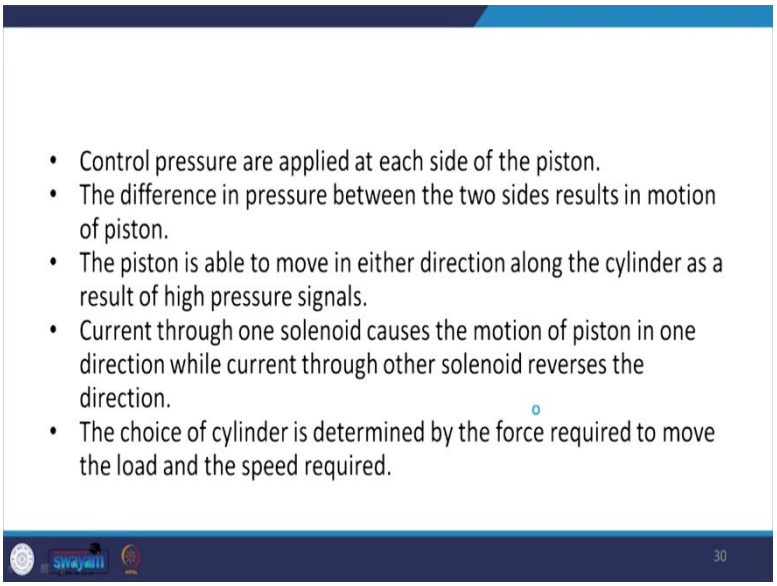

So, control pressure is applied at each side of the piston, the difference in pressure between the two sides results in the motion of the piston. And, the piston is able to move in either direction along with the cylinder as a result of the high-pressure signal. And, the current through one solenoid causes the motion of the piston in one direction, while the current through the other solenoid reverses that direction. The choice of the cylinder is determined by the force required to move the load and at the required speed.

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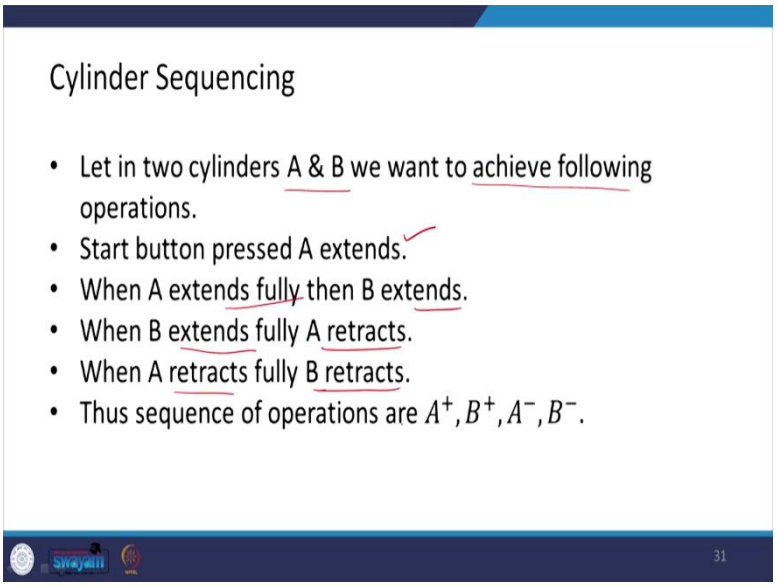

There could be a cylinder sequencing operation also. I am not going to talk much in detail, you can refer to mechatronics by Bolton if you are further interested in how the cylinder sequencing could be done.

If we two cylinders A and B, and we want to achieve the following operation say the start button pressed A, cylinder A extends, when A extends fully then say B extends when B extends fully. Then, say A retracts when a retracts fully, then say B retracts so, we could have various combinations of sequencing.

This type of thing extension is represented by plus '+' retraction represented by a '- 'sign here. So, this type of cylinder sequencing can also be implemented with the help of a hydraulic cylinder.

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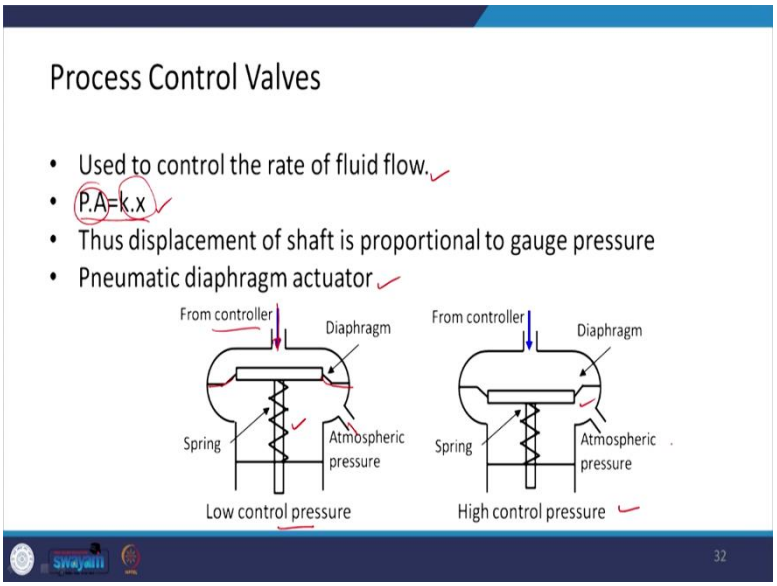

Next, let us lo at the process control valve. These are used to control the rate of fluid flow. And, in this case, what is what happens is there is a diaphragm as you can see over here, this side is connected to the controller. There is a spring over here, this is atmospheric pressure to this side and there is low control pressure is there.

So, in this case,

$$P.\ A = k\ x$$

this is the principle used. This force is because of the pressure and this is the spring force. The displacement of the shaft is proportional to gauge pressure and these are also called pneumatic diaphragm actuators. So, in case of the high control pressure, you could have this type of configuration.

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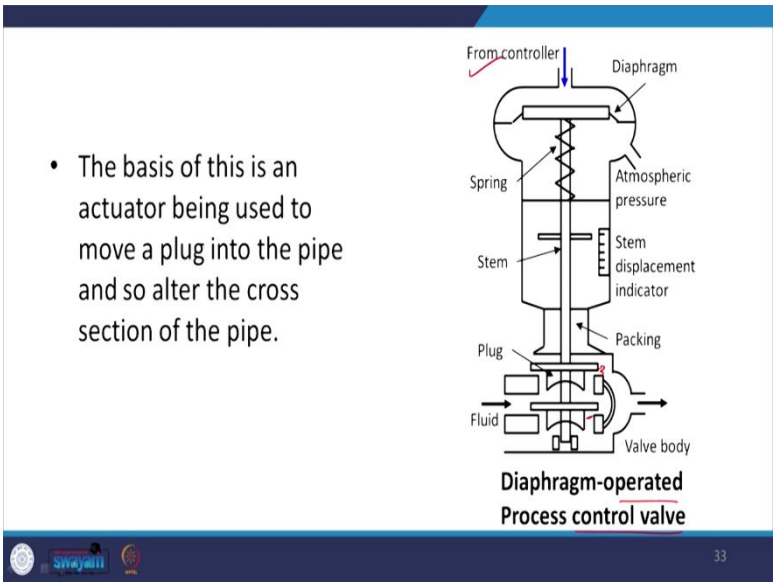

And, these types of devices that are the process control valve, could be used to operate certain valves such as diaphragm operated process control valves. Here, you can see that some fluid is going, and here is a valve, and this valve could be controlled with the help of this device from the controller.

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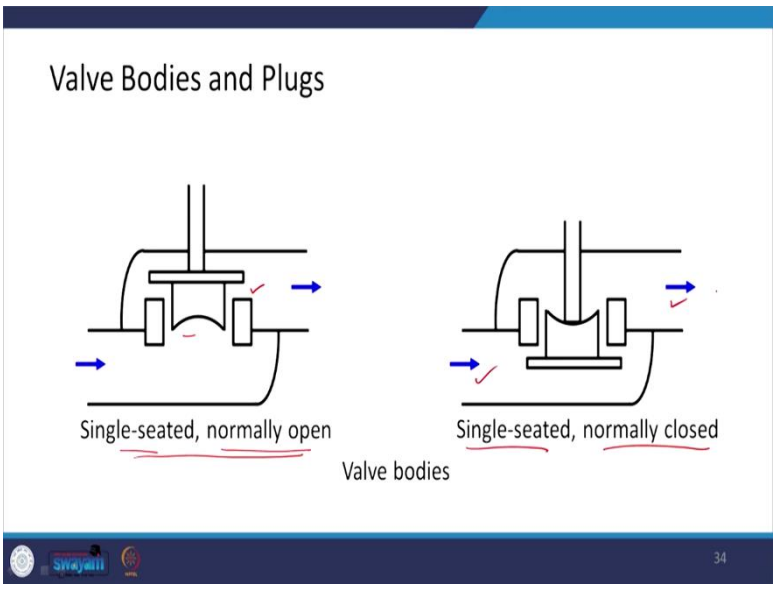

There are various types of valve bodies and plugs, this is a single-seated normally open. In this, there is only one seat and normally this is open condition. So, this is called single-

seated normally open and this is single-seated and this is normally closed condition. So, in normal conditions liquid cannot flow from this side to this side.

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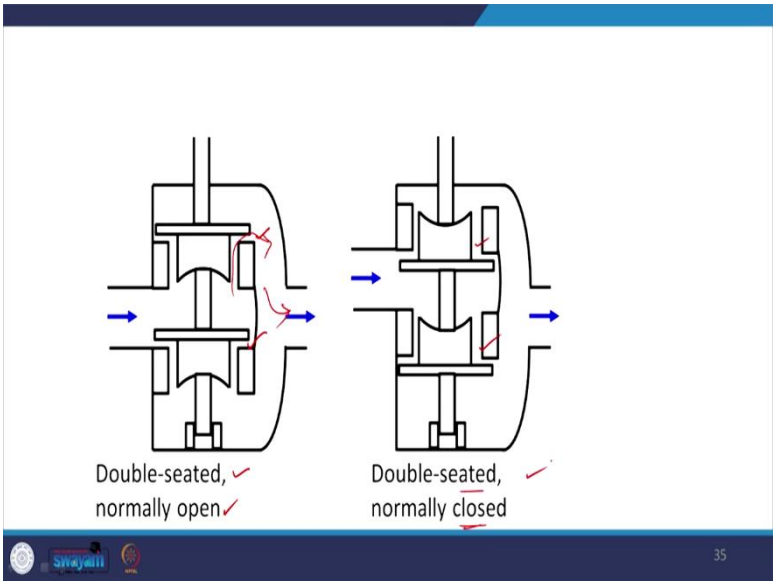

Then, we have double-seated, there are double seats one seat here, another seat here. So, this is called double seated and normally open. It is normally open so, the liquid can flow this way. And, this is the double-seated that is a seat here and here and this is the normally closed configuration.

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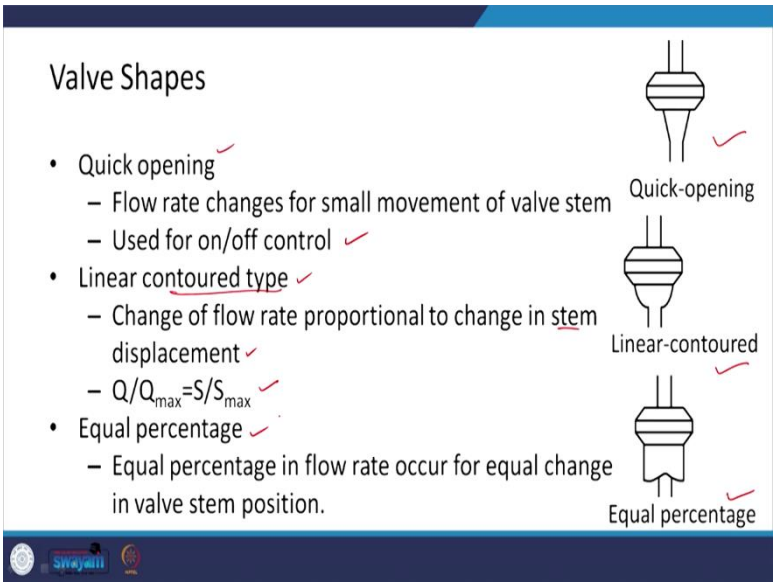

There are various shapes of the valve for quick opening, linear contoured, and equal percentage. These types of quick opening valve flow rate change for a small movement of the valve stem as the name indicates, they are quick reckoning and these are used for the on-off control. Then, in the linear contoured type, the change of flow rate is proportional to the change in a stem displacement.

And so, you have,

$$\frac{Q}{Q_{max}} = \frac{S}{S_{max}}$$

Applicable in the linear contoured type, where S is the stem displacement and Q is the flow rate. The equal percentage of flow rate occurs for an equal change in the valve stem position.

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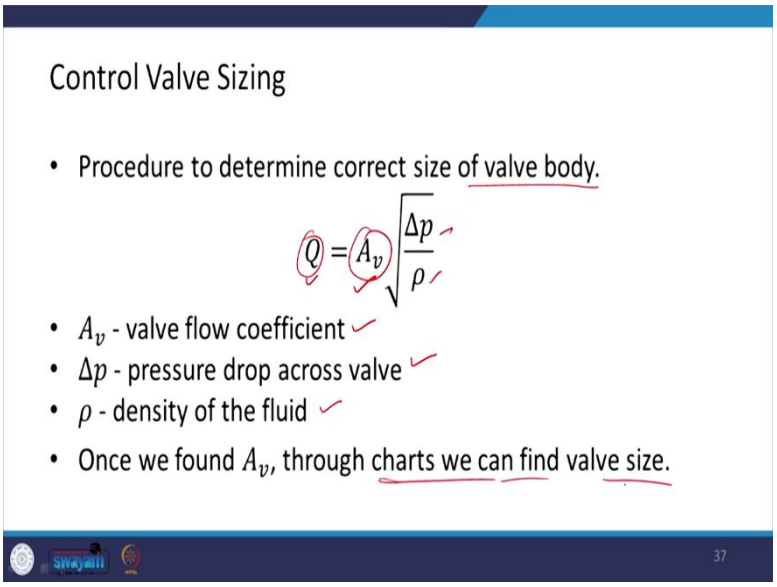

Then, we can also look at the control valve sizing. The procedure to determine the correct size of the valve body,

the relationship for discharge (Q) = $A_v\sqrt{\frac{\Delta p}{\rho}}$

where A_v is the valve rate flow coefficient, Δp is the pressure drop across the valve and ρ is the density of the fluid. So, if I know the Q value and I will know this value, I can find out A_v and if I know the A_v, then I can use the chart to find out the valve size of the valve.

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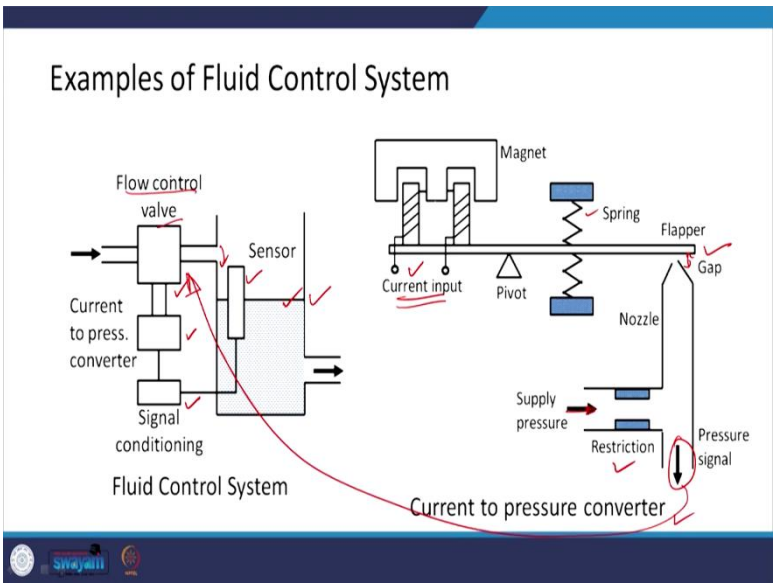

Let us take an example of the fluid control system. In the fluid control system, suppose I want to control the level of water in this tank. So, I put a sensor and the sensor signal is sent to the signal conditioning unit. And, this is then sent to the current to the pressure converter, and then the pressure output is the pressure and that controls the flow control valve. And that valve opening and closing of the flow control valve, and in this way, the level of water in this tank can be maintained constant.

The current to pressure converter could look something like this, you have the current input here. There is a pivot and there is a spring here and there is a flapper here. So, you could have a restriction here, you supply pressure through a restriction. And based on the gap over here, which is maintained with the help of the current input here, you could have the pressure signal. And this signal can be used here to control the flow.

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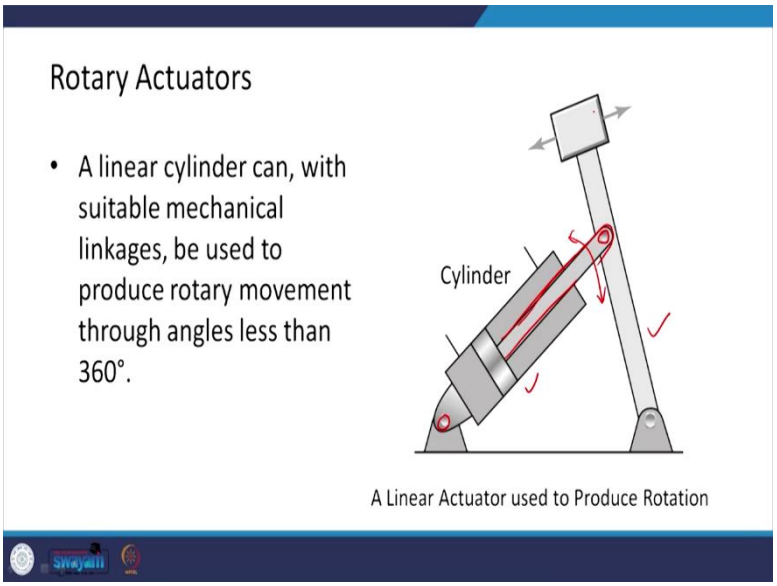

There are rotary actuators. They have a cylinder and piston arrangement. And this cylinder this your piston could be used to drive some lever over here. In this way, we are converting this piston motion into this thing rotary motion.

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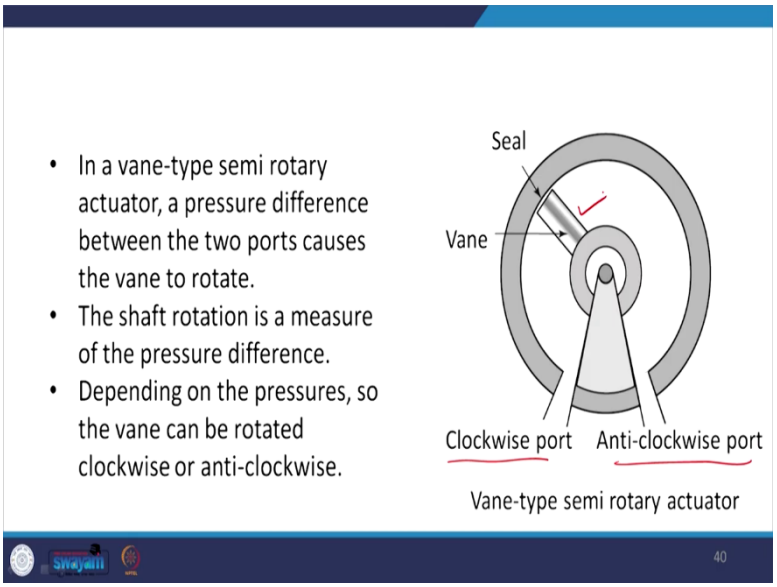

Then, we could have a various vane type semi-rotary actuator, a pressure difference between the two ports causes the vane to rotate and the shaft rotation is the measure of the pressure difference. And depending on the pressure, the vane can be rotated clockwise or

anti-clockwise. So, essentially it has got a clockwise port and anti-clockwise port and there is a vane .

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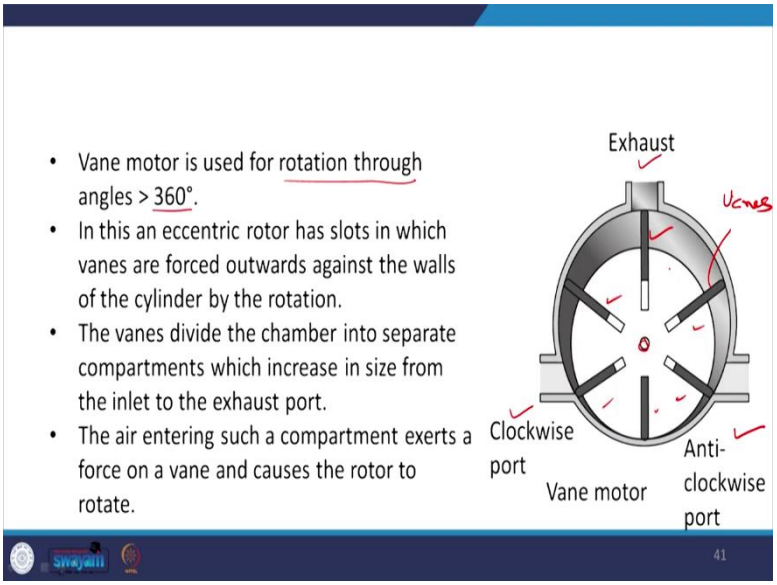

So, this is the vane type of rotary actuator. The vane motor is used for rotation if we are looking for rotation more than 360 degrees. And in this eccentric rotor has slots in which the vanes are forced, outward against the valve of the cylinder. So, here you can see that these are the vanes. And, these are forced across the valve of the cylinder.

Now, again here you have the clockwise port, you have the anti-clockwise port and here these are the vanes, and you have the exhaust here. So, the vanes divide this chamber into different compartments, which increase in size from the inlet to the outlet port. And the air entering such a compartment exerts a force on the vane and causes the rotor to rotate.

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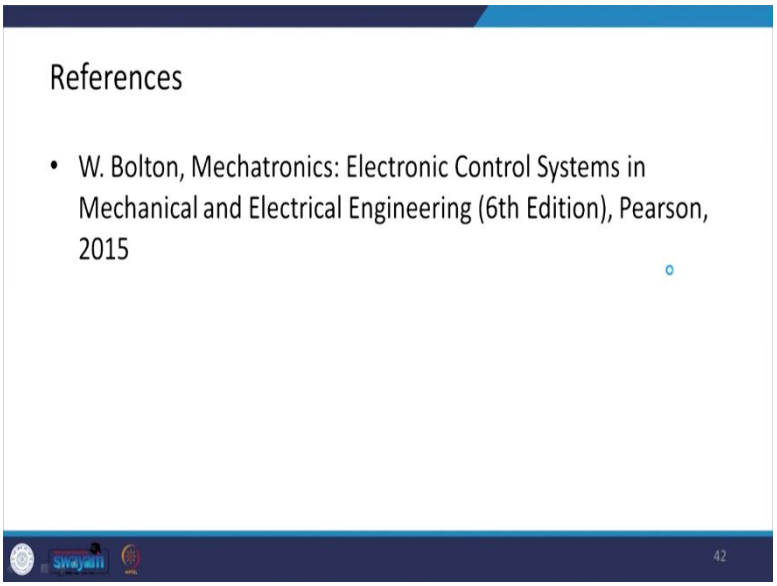

If you want to read more and get further details, you can refer to the mechatronics by Bolton for further reading so.

Thank you.