Fundamentals of Industrial Oil Hydraulics and Pneumatics
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Module04 Lecture10
Hydraulic Servomechanism and Servo and Proportional Control Valves

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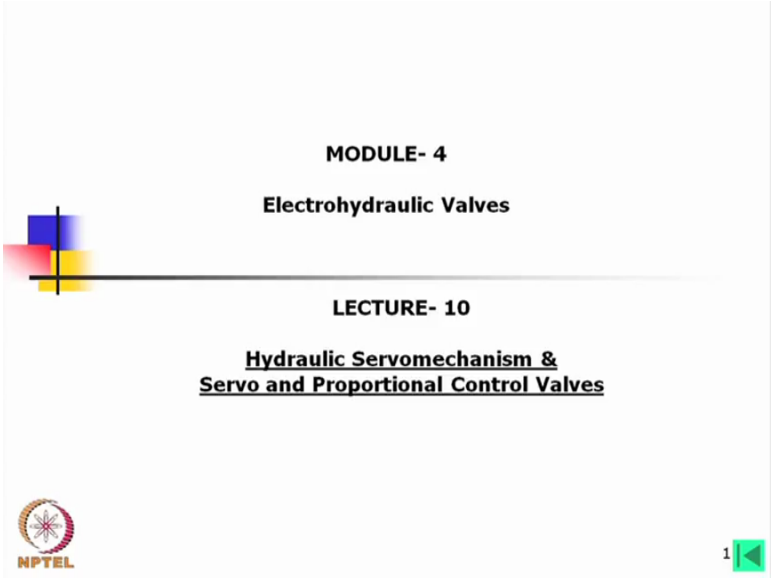

Welcome to today's lecture on industrial oil hydraulics and pneumatics. Today's topic will be hydraulic servomechanism and servo and proportional control valves.

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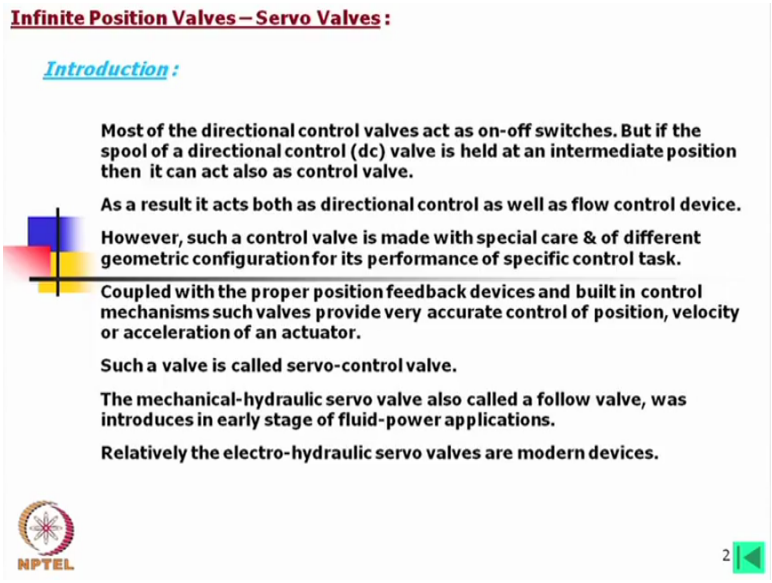

Now most of the directional control valves acts as on-off switches, but if the spool of a directional control valve or which is called also dc valve is held at an intermediate position then it can act also as control valve. Control means in this sense infinite control valve. So on-off even on-off itself is a control, which is just one or zero or zero or one it is like that. In that case you will get some intermediate positions to control the flow as well as the pressure. As a result, it acts both as directional control as well as flow control device. However, such a control valve is made with special care and of different geometric configuration for its performance of specific control task. Coupled with the proper position feedback devices and built in control mechanism such valves provide very accurate control of position, velocity or acceleration of an actuator.

Now the servo control term as you know that basically means feedback control of position and velocity. So this are introduction to we can say the servo valve. Such a valve is called servo control valve. The mechanical hydraulic servo valve also called a follow valve. It is called follow valve was introduced in early stage of fluid power applications. Relatively the electrohydraulic servo valves are modern devices.

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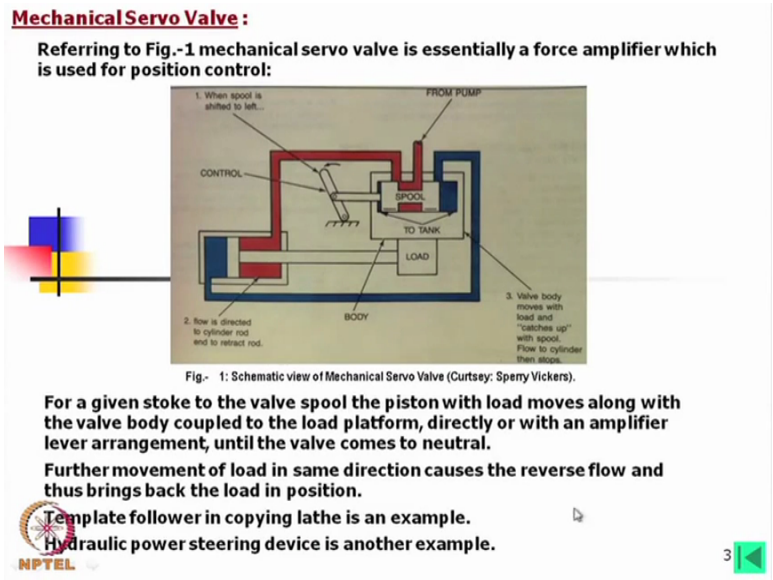

Now if we look into this figure, then this is a mechanical servo valve and it is essentially a force amplifier which is used for position control. Now what we look into this scheme. This is a schematic view is a figure of a hydraulic circuit. Now what we find here, this is a cylinder and this is the high pressure side, this is a low pressure side and here is the load, okay. Now this valve we may consider it is an ordinary directional control valve, but this valve can be used as also the servo mechanical valve. How?

It is like that we allow say by we have given an input. First of all we have to give an input. Now if let us consider if it is at the vertical position, okay. In that vertical position what will happen the oil will come to this chamber. This is a very schematic actually this may not function if we take just a spool like this, but let us consider it is in the neutral position and then oil from the pump is coming inside, but it cannot go this way or neither it cannot go other way, okay. So in that way there is of course the drain passage which are not shown.

Now if we give a little moment in the left ward directions. So this will open once this opens then the oil will go to this portions and this load will move. Now look at this, this here it is a written a this tank, this small chambers you can say chambers, but what actually will happen this valve body not the spool valve body will move in this direction then, it will be closed again. So there will be no motion of the valve, but this input is given that means this is in a manner the constant input is there, for example if we use a solenoid the constant input is there, certain amount of input is there. So due to this input again this will open and again this valve and it will close and this will go on and that will occur simultaneously and shows mostly that there will be no discrete motion of this body not the valve.

So this is basically we should call servo mechanical servo valve hydro mechanical servo valve and this principle is used in many places, including that copying machines copying of say lath. In lath, in copying process this hydro mechanical servo valve is used, okay. For example, if this is fitted over a the template, a following this template it will this their feed is through the template and automatically this will move. For a given stroke to the valve spool the piston with load moves along with the valve body coupled to the load platform, directly or with an amplifier lever arrangement until the valve comes to neutral. Here it is a direct connection that means what is the moment of this piston the moment of this body will be same, but it can be also amplified or reduces.

Normally amplification is required for which this means that suppose this moves 10 millimeter then this will move only one millimeter, because valve moment is very small we need. So that can be done by a fixed mechanism system or may be variable system also. The ratio where the ratio can be varying. Further moment of load in same direction causes the reverse flow and thus brings back the load in position. Now we have shown the motion, but what will happen, if it moves further I mean excess moment whatever the desired motion that means whatever the flow rate is given here this controlling the velocity. In that case, if it moves further than other side opens that means oil is going to the other side and then what

will happen this will move in the opposite directions. Thus not only that this position control also will be maintain that means the velocity constant velocity will be maintained. Now this happens together.

Now if there is no sensor of course then there is a possibility of drift that means after sometimes it may not match. Actually there will be positioning sensors and along with that there will be some corrections which is called feedback control to the input side also. However, if you remove this input then it will be in again in this (())(9:40) position. Template follower in copying lath is an example which I have already told you. Hydraulic power steering device is another example. In case of hydraulic power steering what we do we give a little moment, 2 things we do, one is that we use a very little effort actual steering force is much higher and again the whatever the steering amount is required, sometimes we give we have to give more rotations to rotate say, suppose if we rotate 90 degree, the steering wheel will rotate only 1that 5 degree. It is like that, that ratio is there. So such magnifications and this following system can be done by hydro-mechanical servo valve.

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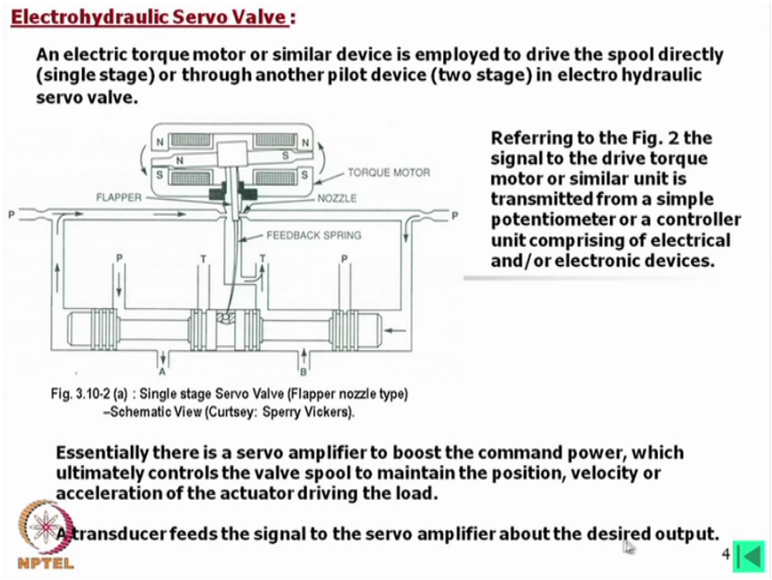

An electric torque motor if we consider the electro-hydraulic servo valve. In that case what happens? The electric torque motor or similar device is employed to drive the spool directly that means single stage or through another pilot device which is 2 stage in electro-hydraulic servo valve. Here I would like to mention in some cases for very large force and very high flow, sometimes the 3 stage valve is used. The first pilot stage operates another stage which is called secondary pilot stage and that pilot stage will ultimately operate the main valve.

Now this is a somewhat schematic view of a single stage servo valve. What we find here that this is a flapper. Now this flapper is giving the motion to the spool. This is moving this way or the other way. Now this is driven by and torque motor what is torque motor you will find that armature and the code is like that. This can give only certain amount of moment, okay. So first what we do that we give suppose we have given a torque like this in this directions, then this valve will okay what we find due to this what is actually happening that flow from this side is coming here and it is going to the tank due to which it is giving the motion apparently in this directions and then this is being closed and this is being opened and then the flow from pressure side is going to A of an actuator and from this side, it is going back to the tank.

Now these both are pressure supply and these two are two ends of the actuator and this is a secondary flow and what is actually happening there. There are two nozzles we have studied a little bit about the flap and nozzle also. In that case what will happen due to this flow there will be differential pressure due to this differential pressure it will always try to keep in a particular position depending on how much torque we have applied here, okay and then this is the inside feedback, you can say the feedback spring. This is called the feedback spring and this is which is being controlled by not only this spring but also this flow here.

However, then on the actuator there will be a position feedback or position velocity transducer will be there, sensors will be there that will again will be fed into this machine which will make some more corrections to make this valve accurate, but servo valve term is such that it may not need the feedback from the used point that means we may not use a sensor there, it is automatically for a given control, suppose if we can calculate say this much input will fulfill the requirements, then we can only give that much input to the system and it will be automatically control by this inner feedback system.

Now referring to this figure, this single the signal to the drive torque motor or similar unit is transmitted from a simple potentiometer or a controller unit comprising of electrical and or electronic devices. If the high torque is required then definitely you have to take this electrical units otherwise ordinary electronic device which can generate small amount of force that also can be used there. Essentially, there is a servo amplifier to boost the command power, which ultimately controls the valve spool to maintain the position, velocity or acceleration of the actuator driving the load. A transducer feeds the signal to the servo amplifier about the desired output. This already I have discussed.

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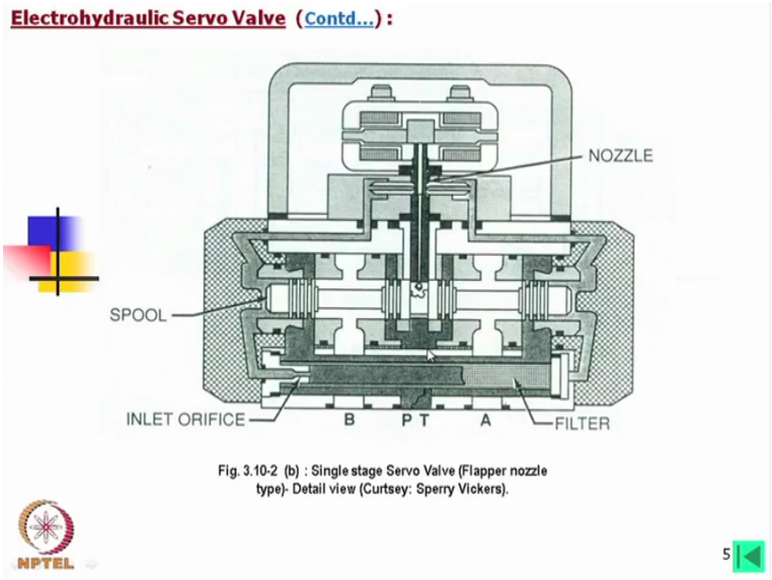

Now this is a more detail view of such a single stage servo valve. Here what we find that the spool is actually we could say this is the drive system and this is the feedback system, but this is only one stage is there, okay. in many cases you will find this much is required for the pilot stage and then this flow what is going to A and B is connected to the two ends of the another spool valve which is the actual flow control valve there. Now as you see these are so detail say where you have to say this is the actually this is the spool and this is a valve body and this is the spring so you can say this flapper and spring. This is the flapper and this is the spring and then this is the armature torque arm and essentially there always a filter is use. So flow is going through these filters okay. Now this filter is an additional filter apart from there will be another filter which is called high pressure filter. This is connected in the line from where the flow is coming to this system.

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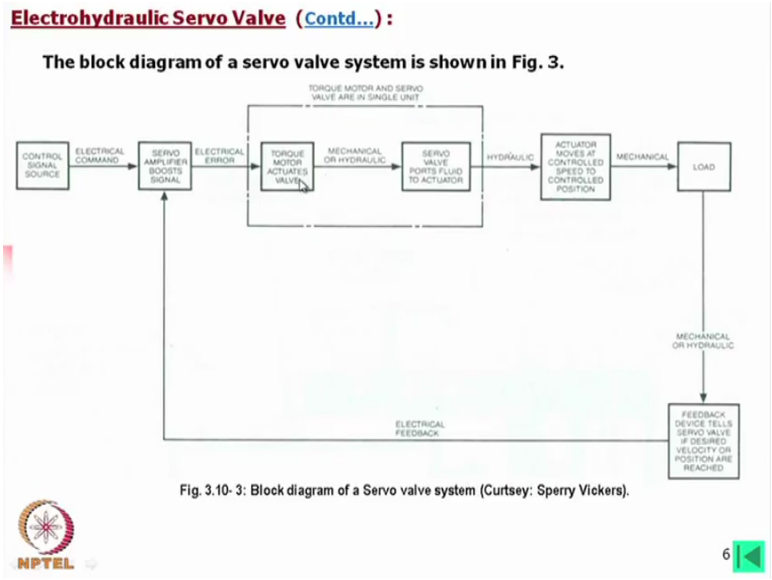

Now if we divide this total function of this valve into discrete manner than we can develop a block diagram for the operation of such a valve. Now what it is that control signal source is along with the electrical command is given to the servo amplifier boost signal. So from there again some error may have there then it is going to the torque motor and then mechanical or hydraulical then we find the servo valve, ports, fluid to actuator, then this is again hydraulic and then actuator moves at controlled speed to controlled positions. So mechanical and then load and load to mechanical or hydraulic again and from there a position feedback or velocity feedback, these are given back to the servo amplifier which make the necessary plus minus corrections according to again the electrical input is varied and then again it is given to the torque motor and thus we get the desired output. So this you can say together are torque motor and servo valve. This is available in as a single unit okay.

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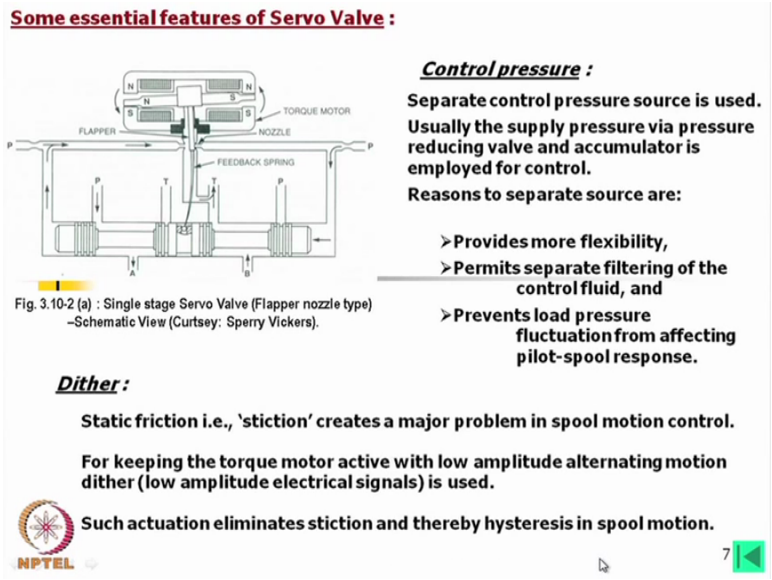

Then we think of this control pressure. Now separate control pressure. That means this source is a separate source not the main source here. Usually the supply pressure via pressure reducing valve and accumulator is employed for control. Reasons to separate source are one, provides more flexibility, secondly permits separate filtering of the control fluid and thirdly prevents load pressure fluctuation load pressure fluctuation from affecting the pilot spool response.

Now another thing is required which is called dither. The static frictions that is stiction creates a major problem in spool motion control. Now what actually happens, both external stiction is there if you think of anything moving on another surface then what happens even if the rolling, there will be some amount of stictions particularly in case of (())(20:47) friction there will be stiction. So that motion is usually called that stick sleep motion. Now in case of this spool moment there is also stiction. The outside stiction whatever there we do not have any control of this valve we cannot have a we can expect a smooth system, but there may have some stiction also higher stiction in the application at also, but however what we are talking about that is the stiction of this spool inside this valve, okay and that creates a major problem. For keeping the torque motor active with low amplitude alternating motion dither low amplitude electrical signals is used.

Now what is actually perhaps happen what I understand this dither using this dither the motion suppose we are trying to move a body like this, but we are moving this with the small vibrations . So application of these dithers that eliminates not eliminates stiction. So a dither along with this electrical system when the torque motor is essential for servo valve. Such

actuation eliminates stiction and thereby hysteresis in spool motion, okay. we can say this is may not be totally eliminate, but it definitely reduces.

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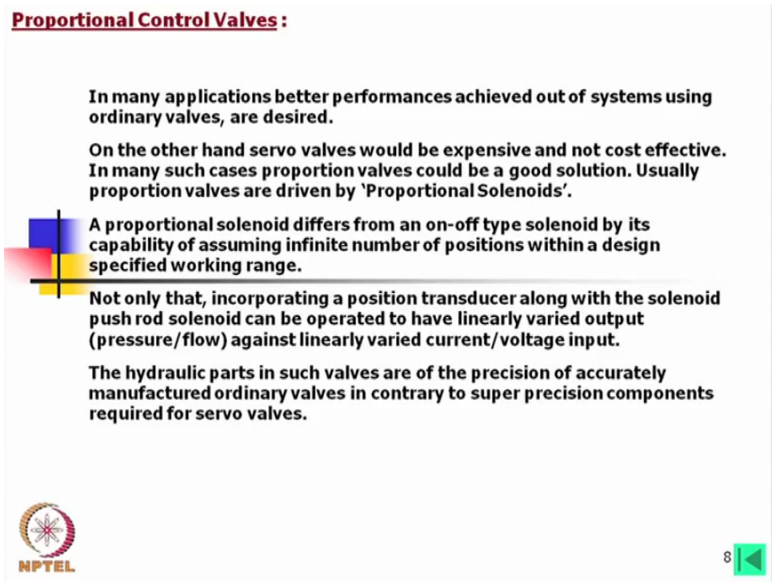

Now we will come to a newer topic which is called proportional control valve. Now that I have already told you that the mechanical servo valve hydro mechanical servo valve it almost devised when the fluid power was introduced, but the electrical servo valves, electro hydraulic servo valves that has come later . Now then servo valve is usually constructed in such a way that feedback control, it is built in inside that means for a given input the output is always controlled and if there is some error that will be corrected inside, so we can get very smooth motion and a desired motion of the device which we are actuating and we ideally we may not use any transducer at the user end. However, these valves are very expensive, because for that feedback control inside and getting desired output the all the components are made vary accurately and that should be very match part.

Now due to that the valve become very expensive and many cases in many applications such valve are used only for that one time say for example, for missile. In case of missile one servo valve is used only for one application, then this servo valve itself is destroyed and these are very expensive. Now the same servo valve mechanism when we are using for daily applications say for example in machine tools. Then when it comes that servo valve is not functioning properly that means inside feedback system is somehow not functioning properly then there is only way we have to reject the valve and we can replace that with a newer valve new valve. Now that becomes very expensive.

Alternatingly, there was another methods of control to that was developed in later stage, may be only in 70s or 80s in the last century that is called proportional control valve. In this proportional control valve the hydraulic part, these are the same as ordinary valve. Although, slightly accurately made, but not like an servo valve components. Now here what happens that the valve is designed in such a way, for a input given input say this is a current input or voltage input to the drive unit that means motor or solenoids whatever is there. The output will be proportionally and proportional means in most of the cases linearly proportional. That means one volt mean 10 mega pascal, 2 volt mean 20 mega pascal pressure or may be flow in that way 10 liter per minutes, 20 liter per minutes.

Now inside of you think that there is may not have linearity and it is not there, but as such the input output is concern this will be linear. So this design is not an easy task, but still it is possible we can give some feedback inside, we can also provide external feedback, we can make the open loop even if we can make it closed loop with an computers, but this proportional valve such mechanism can work like an servo valve although, the finer accuracy may not be that much or in other words what we can get with the servo valve if we consider that is a 100 percent we may get similar output with an proportional valve at least upto the 95 percents and in most of the cases that (())(27:12) this means that in case of machine tools sometimes this will work and many other applications also this will work not only that if you think from the other side where, apparently it is felt that servo valve should give the better performance, but the servo valve is very expensive there we can use an proportional control valve and it will give the better performance than the ordinary valve although, it may not give the what the servo valve can give.

Now this proportional control valve how it works? In many applications better performances achieved out of the systems using ordinary valves as desired. On the other hand, servo valves would be expensive and not cost effective. In many such cases, proportion valves could be a good solution. Usually proportion valves are driven by proportional solenoids; sometimes we use the phrase proportional control solenoids. In case of proportional control valves also sometimes it call simply proportional valve.

A proportional solenoid differs from an on-off type solenoid. Most of the case what we find that electrically actuated valves ordinary on-off type valve they are also solenoid is used, but that is on-off type solenoid. If you give the input the solenoid will actuate fully and it will

operate say this will on that valve and if you put off the current, then this will be off that means the solenoid armature will be fully retracted and it will be off.

In case of proportional solenoid depending on the current the motion will be proportional, but here this motion may not be linear, we are giving one volt for that first one volt you may find that the solenoid is moving say 1 millimeter. Next another volt you will find, it has moved further 0.8 millimeter. Next 1 volt that is 3 volt input you may find is has moved another 0.7 millimeter, it is like that, that may not be will the linear. However, due to that motion then whatever it is controlling, this is definitely controlling a pilot spool. The pilot spool is being controlled in such a way that would ultimate output may be pressure control or may be the flow control that will be linear to this input, okay. Do not confuse with that this will be also the linear.

Not only that, incorporating a position transducer along with the solenoid push rod. Solenoid can be operated to have linearly varied output pressure or flow against linearly varied current and voltage input. This means that usually in case of proportional valve there is a feedback control for the armature. That means it transduces position of the solenoid and then it corrects inside to give the motions that means if it is already recorded that for one volt one millimeter motion. So for that controlling that part there is a feedback system inside, but it is also possible from the externally it can be controlled. What happens we can develop a control algorithm as the input output is linear so that will give the that will calculate vary accurately what will be the input and output or what are the corrections very first.

Although, it may not be like a servo valve, so servo valve response may be better than proportional valve, but it will calculate with not much affecting the system, say for example, if we use a servo valve for the thickness control in a rolling mill where the seat metal is being manufactured. If we use a servo valve probably if there is an error the defective products and that say different of thickness products and may be of 1 meter length at the most and then by that time it will be corrected. If we use the proportional control valve, probably there will be 3-4 meters of length that is a little defective as a thickness is more than desired thickness or less than desired thickness whatever it might be. So but that may not be may not affect the total production volume. The hydraulic parts is in such valves are of the precision of accurately manufacture ordinary valves, in contrary to super precision components required for servo valves.

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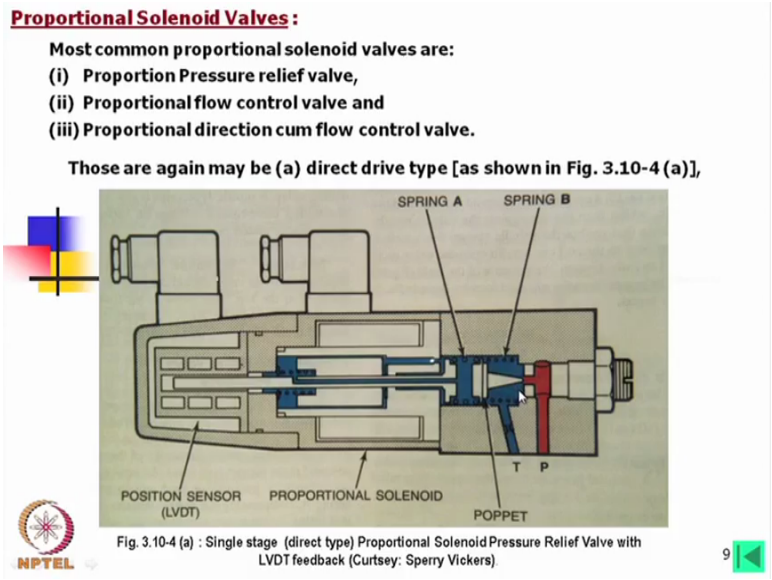

Now most common proportional solenoid valves are, the proportion pressure relief valve, this is one. This means that in this case we can control the pressure proportionally to the input say total range of the system say it will be from we would like to operate from 5 mega pascal to 15 mega pascal and our current may be for that we will varying from 2 to 8 volt or microvolt mainly volt, sorry 2 to 8 millivolt like that. Now due to that much of change we will get this output proportionally. This means that in case of setting the relief valve at a particular pressures we can vary that depending on the load we are handling and by that process we can save the energy also, because reliving at a low pressure will be less energy will be loss.

Secondly, proportional flow control valves and thirdly, the proportional direction cum flow control valve, okay. This means that what is proportional direction control that is that we are controlling this direction with a controlled flow that is some proportionate, it is some proportion not the full that is why this term proportional flow. Proportional flow control is okay by proportional direction control, because direction will be either left or right, up and low. A single valve cannot move in all directions. Anyway the term is proportional direction cum flow control valve.

Now here is a direct drive proportional control valve. Those are again may be direct type as shown in this figure and direct type means; here this is the proportional solenoid, okay. So this is an input to this proportional solenoid and this is input to the feedback system. Now this is position sensor this one is the position sensor. So this is input to the position sensor. This is actually the proportional solenoid and here as we find that this is the spool and ultimately it is controlling this one. So this is acting as a pressure relief valve. What is there according to the

current input, this poppet will be controlled and then this will allow the this orifice will open by a certain amount and in that way, the relief valve control will be there.

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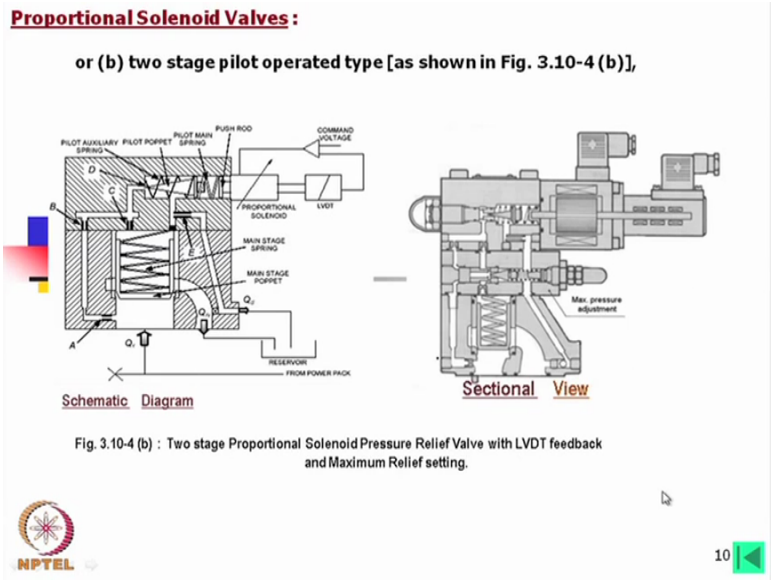

So this is a direct type, but this direct type has other problem as we know direct pressure relief valve is not good for controlling I mean there may have instability. Although, in proportional control valve it is less than a ordinary valve, but still it will be there. So where we need more stability and very varied pressuring range or frequent varying pressuring range in that case we will prefer 2 stage pilot operated type valve. Now this is this looks like a this is you can say sectional view although, it is not the original section, but on a real shape you can say.

Now here this is the proportional solenoid and this is the transducer part or you can say that is feedback part which controls which gives the feedback and then further it controls the control unit is outside and sometimes also the control unit is inside or in other words I would say in this case, there cart to drive these two and in that cart there will be control position feedback control of this solenoid that means this spool end. Now there is a what we find there is a main spring and this is this spring is to just to positioned in this poppet and this is the varying orifice which is controlling the orifice size and by that this pressure control.

Now this is an additional part. This we can keep or may not keep. This is ordinary pressure relief valve for maximum setting we keep it suppose the system will work from 5 mega pascal to 10 mega pascal then; this setting will be a 10 mega pascal. So when if this does not function then this valve will function and then the relief will be there or this is for extra safety

device. However, we can remove this say let us this is removed and then what we find that there are orifices, okay I shall describe this with a with an schematic view. If we look into this schematic view where this part is removed then what we find here you can compare with this figure. Here we find a orifice, this is we cn change this orifice, so this is as if the external insert (())(39:03) is there, but there is an permanent orifice too and after that there is another orifice and then this is the variable orifice and then this orifice is connected to this other end of the main spool and then this is the leakage flow which is going through an capillary passage and to the chamber.

Now this is the system lien and it is connected here. What happens in normal condition suppose, this is we have given an input to control this 7 mega pascal. The system is working at 5 mega pascal ta that moment requirements. So 5 mega pascal pressure is coming over here. Now this flow is going here, here, here, here, it is connected. Now as this is set with a some current to have the 7 mega pascal control. So definitely force is more and this is closed. This is remain closed or very slightly open to give a constant flow through this as there is a constant flow there will be a pressure drop in this side and then due to this differential pressure still it will remain closed. The spring force and differential pressure force whatever pressure here, this pressure will be less, but there is a additional spring so that spring force plus this pressure force is more than this force. So it will remain closed.

Now suppose this increases pressure increases then what will happen? The more force will be here, orifice size increase more flow will be there, more pressure drop will be there and then this at one point the spring force and this pressure force will be less than the force here and then this will be lifted oil will be go through this. Now this is working on the differential pressure both side thee is a force, but one force is less than the other and that is why very small control unit. So therefore the stability of the spool will be more than the directly valve. Why we need such things, because when the flow begins definitely pressure drops here. So due to this pressure drop again it will try to close, but due to this differential pressure process it will not ordinarily closed very quietly. So it will remain in stable condition for a longer time. So this is the basic function of the proportional valve and we will learn it more in the when we have detail discuss on the function of proportional valve.

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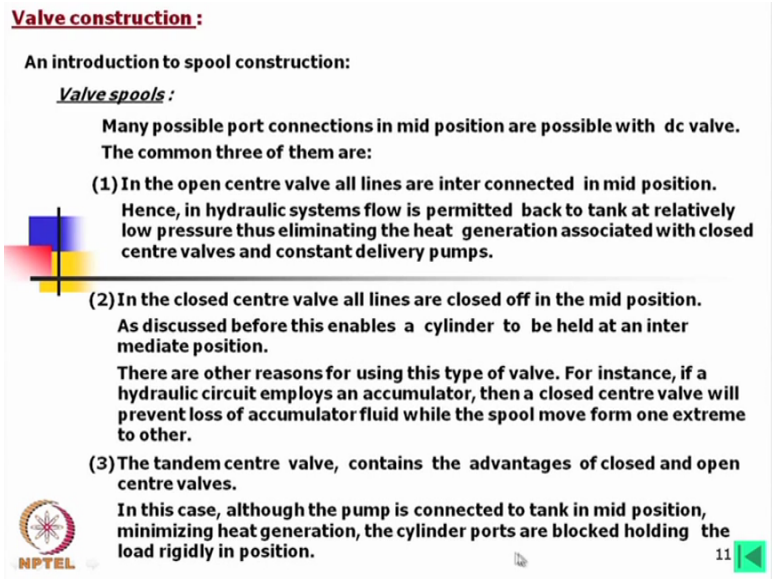

Now an introduction to spool construction. Now although we should say that we are thinking of the valve constructions, but in this lecture I shall cover only the how the spool is manufactured? How we can maintain such accuracy in case of spool and that is mostly related to servo valve spool. Now valve spool, many possible port connection in mid positions are possible with dc valve, dc valve direction control valve we can make it on-off and we can make it the infinite position control and again it might be close port, open port, fully closed, partially closed many many such things. So while we are designing such spool we have to take care of both functional aspect and also material aspects.

The common three of them that positions, in the open centre valve all lines are interconnected in mid positions that we know. Hence, in hydraulic systems flow is permitted back to tank at relatively low pressure. Thus eliminating the heat generation associated with closed centre valves and constant delivery pumps. In the closed centre valve on the other hand all lines are closed off in the mid positions, as discussed before this enables a cylinder to be held at an intermediate position say benefit of being a closed centre that not only the fluid becomes ready, but we can keep the actuator at the current position.

There are other reasons for using this type of valve for instance, if a hydraulic circuit employs an actuator, then a closed centre valve will prevent loss of accumulator fluid while the spool move from one extream to other. The tandem centre valve contains the advantage of closed and open centre valves. It has the centre actuator side centre will given closed, but the pump

to tank will remain open in case of tandem valve that saves the energy as well as keep the work load at current positions, but by that we lose some other advantage of being closed centre valve. In this case although, the pump is connected to tank in mid positions minimizing heat generation the cylinder ports are blocked holding the load rigidly in position.

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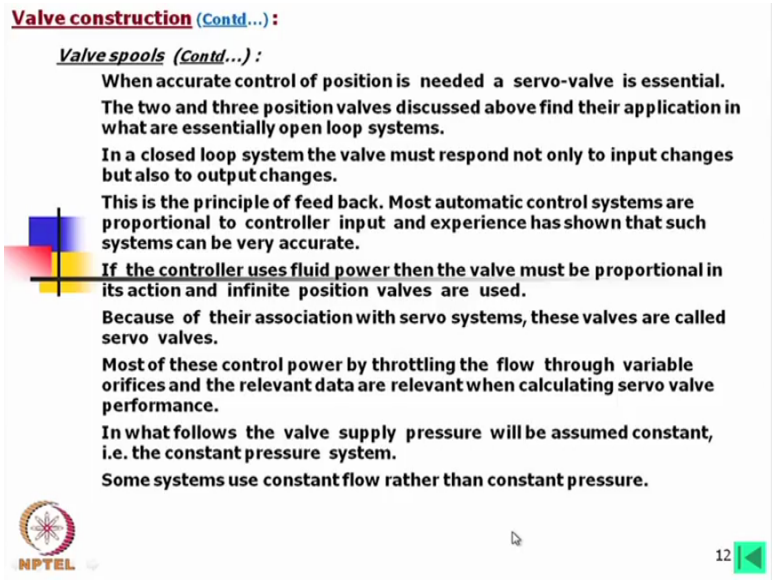

Now valve spool when accurate control of position is needed a servo valve is essential. The two and three position valves discussed earlier find their application in what are essentially open loop systems. In a closed loop systems the valve must respond not only to input changes but also to output changes. This is the principle of feedback, most automatic control systems are proportional to controller input and experience has shown that such systems can be very accurate.

If the controller uses fluid power then the valve must be proportional in its action and infinite position valves are used. Because of their association with servo systems these valves are called servo valves and most of these control power by throttling the flow through variable orifices and the relevant data are relevant when calculating servo valve performance. In what follows the valve supply pressure will be assumed constant, the constant pressure system. Some systems use constant flow rather than constant pressure. These are I would say that either we can follow a constant pressure system where the pressure is controlled to a certain limit and in other cases we can also go for the flow control where flow remain constant for an operating zone.

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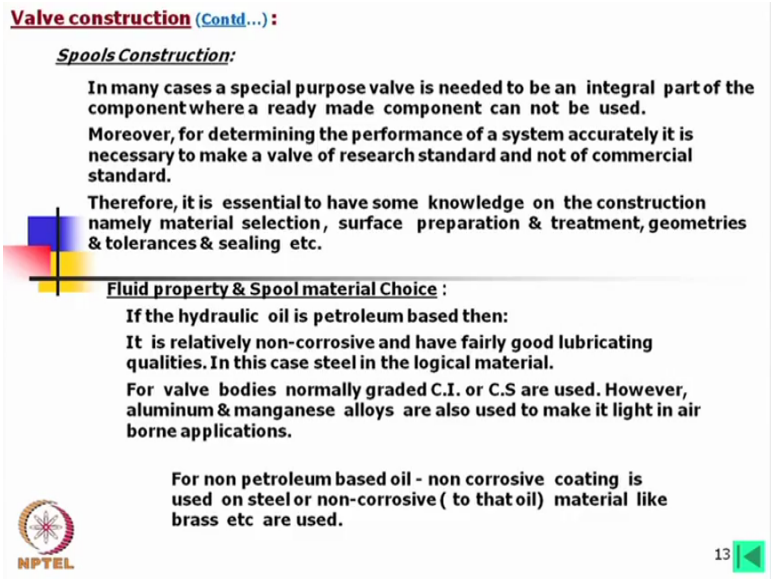

Now the spool constructions say little bit about how this spools is constructed. In many cases a special purpose valve is needed to be an integral part of the component where a ready-made component cannot be used. Moreover, for determining the performance of a system accurately it is necessary to make a valve of research standard and not of commercial standard. Therefore, it is essential to have some knowledge on the construction namely material selection, surface preparations and treatment, geometric and tolerances and sealing etcetera.

Now fluid property and spool material choice. Normally spools are made of steel. Now if the hydraulic oil is petroleum based then it is relatively non-corrosive and have fairly good lubricating qualities. In this case steel is the logical material. For valve bodies normally graded C.I and C.S are used. That means cast iron graded cast iron or we can go for cast steel. However, aluminum, manganese alloy are also used to make it light in air borne applications. For non-petroleum based oil, non-corrosive coating is used on steel or non-corrosive to that oil material like brass etcetera are used.

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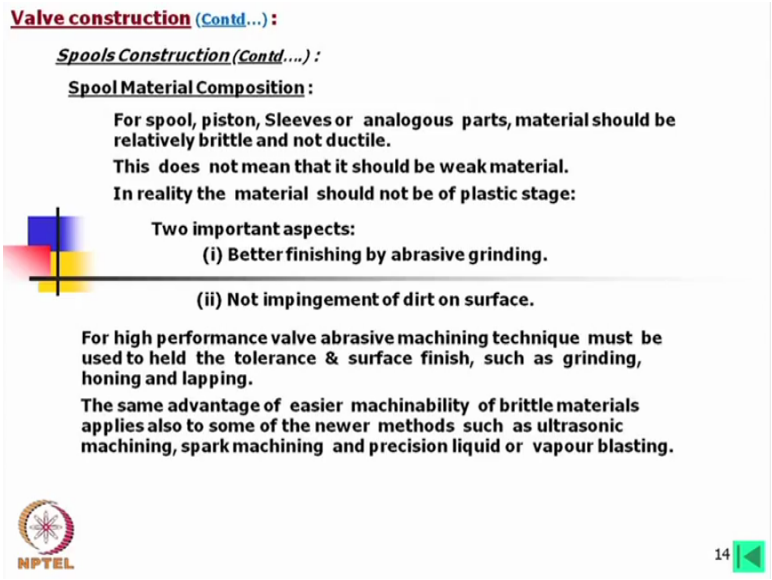

Now spool material composition. This is not a detail composition, but I will give you some idea for spool pistons, sleeves or analogues parts, material should be relatively brittle and not ductile. Why ductile? Why not ductile we can say that there are reasons. This does not mean that it should be weak material. In reality, the material should not be of plastic stage, two important aspects, in that we should consider for the above mentions requirements. Better finishing by abrasive grinding. So first thing we should have very good finishings and for abrasive grinding brittle material will be better than the very ductile material.

Secondly not impingement of dirt on surface, if it is a ductile then there is a possibility this particle will impinged on the surface and that will (())(50:18) the function of this spool. For high performance valve abrasive machining technique must be used to held the tolerance and surface finish such as grinding, horning and lapping. The same advantage of easier machinability of brittle materials applies also to some of the newer methods such as ultrasonic machining, spark machining and precision liquid or vapour blasting.

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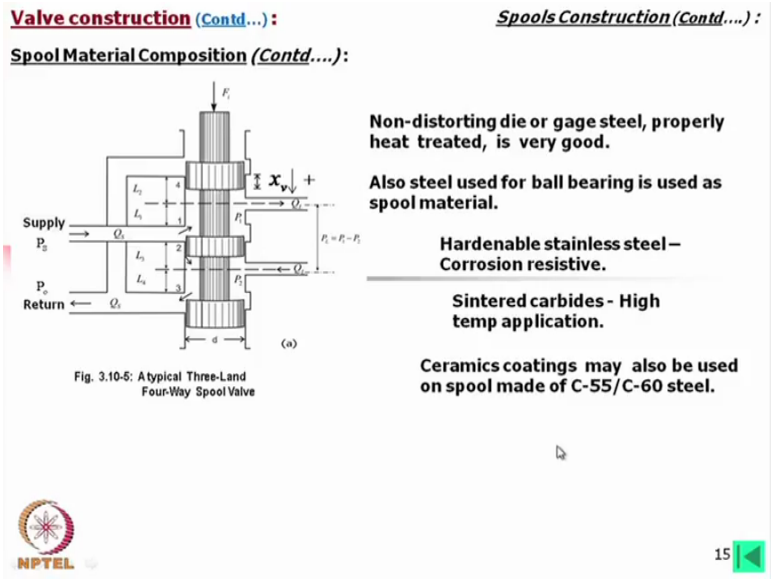

Now non-distorting die or gage steel, properly heat treated is very good for spool. Also we can use the steel which is used for ball bearing. Hardnable stainless steel is corrosive corrosion resistive, so that also can be used. Sintered carbides is used for high temperature applications. Also we can use relatively high carbon steel say C45, C60with ceramic coating on it. Nowadays coating technology has developed so much. So witch material and then coating may also be used that may reduce the cost in mass production.

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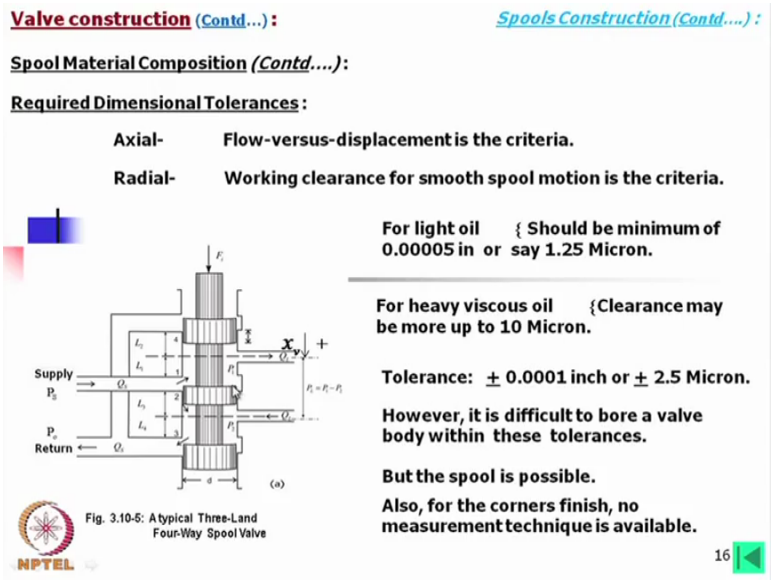

Now what are the required tolerances? First of all the axial in case of servo spool valve or relatively accurately manufactured spool for proportional valve the position of these port on the sleeve and position of this lands on the spool is very important which will control one is the axial flow say axial flow means this side flow. Flow verses displacement is the criteria for axial selecting the axial tolerances and there is of course, the radial tolerances that means how much tolerances will be there. That which is working clearance for smooth spool motion is the criteria to decide the radial clearance.

Now for light oil, these tolerances should be say 1.25 micron at the most. However, we can for every viscous oil we can go upto 10 micron. Tolerances of on this plus minus 2.5 micron where we are suing 10 micron clearances. However, it is difficult to bore a valve body with these tolerances, okay. That means boring of this sleeve making this bore is difficult. However, we can make this spool of such tolerances that is we are grinding externally, it is possible, okay, but there is another problem which si that this corner finish. In case of spool we can control somewhat, but in case of internal there it is very very difficult to control such these corners.

Now surf corners is better for the performance point of view, but surf corners may create the breakage of the corners and then by that the jamming the spool inside. So material is selected material heat treatment etcetera is selected, in such a way that after such machining the corner whatever may be there finish that should not break easily. On the other hand this we cannot chamfered say land corner we machine it and, but this is rounded given a small rounding of that can be controlled for spool manufacturing.

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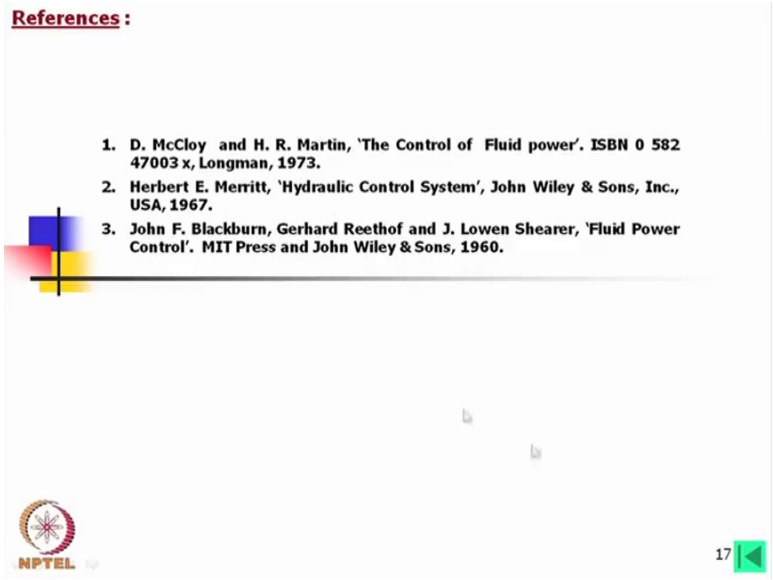

So I would say this is only an little idea about the what is servo valve? What is proportional valve and work? What care must be taken has manufacturing there the hydraulic components only and I have followed the following books for preparing this note. So and you will find mostly all three books may be consulted for this introductory note and thank you.