INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and
Control

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Topic Lecture – 36
Hydraulic Control Systems - II

Welcome to lesson 27 of industrial automation and control.

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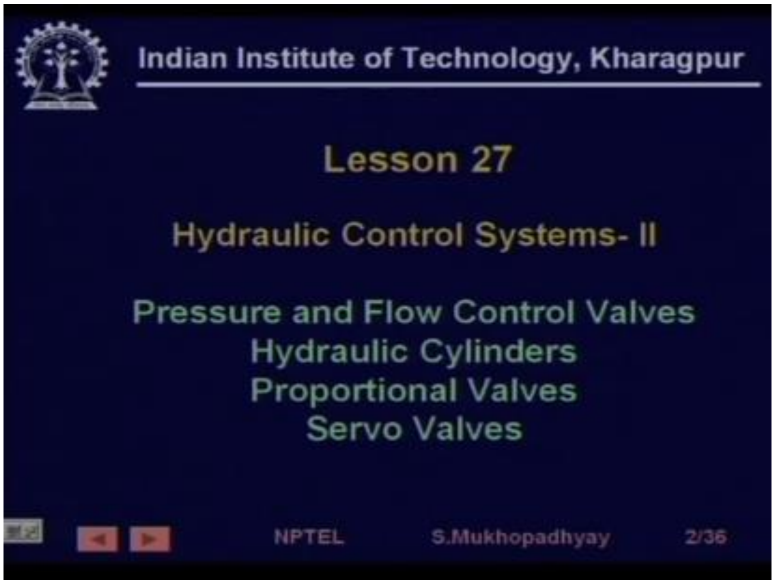

In this lecture we will first look at pressure and flow control valves something which spilled over from the last lecture then look at hydraulic cylinders proportional valves and servo valves and finally we will look at the structure of a full you know hydraulic actuation system so we look at the instruction objectives.

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Describe the principles of operation of pressure and flow control valves and cylinders basic components of proportional valves learn about basic components of servo valves and be familiar with the typical you know control architecture of hydraulic actuation systems these are the instructional objectives of this lesson.

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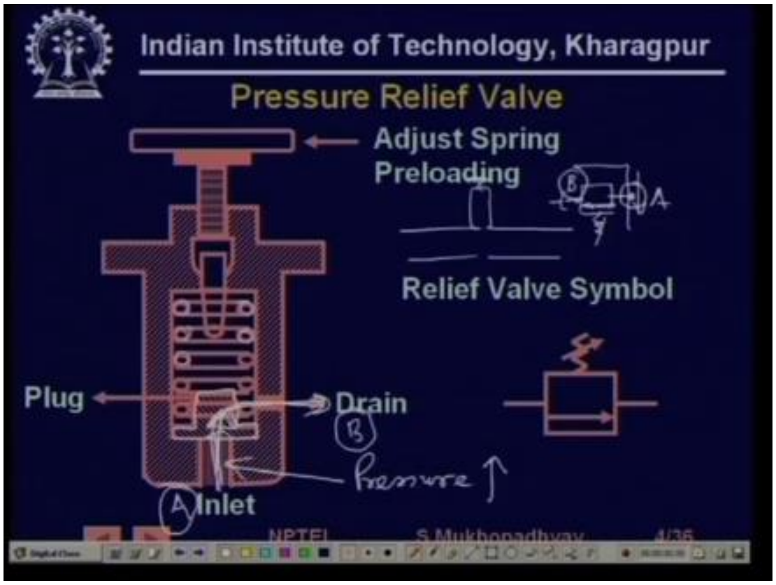

So coming over from the last lesson pressure relief valves these are these valves are typically mounted so you have these are not valves where these are connected in parallel in general that is you have a pipe through which the main flow takes place and this valve is going to be connected in parallel okay, so in a hydraulic circuit you will have the main line and you will have a pressure relief valve connected to typically to tank so this will be the valve symbol as shown and there is an adjustable spring.

So the main power line through which the main fluid flows will be this if the pressure at this point goes high then this valve is supposed to operate so this point A is connected to the inlet a and this point B is connected to the drain B okay so if the pressure goes high here this is a simply a puppet like thing this one which is loaded by this spring this is a spring you can see the cross section so the spring actually presses it down the spring presses it down so when it presses it down this is closed but if the pressure at this point pressure goes high then this will be pushed up this will be pushed up and the fluid will flow through this to the drain it will flow through this to the drain.

So that is the path this path this is the operation of the pressure relief valve now sometimes you need to operate these relief valves in various modes using a pilot.

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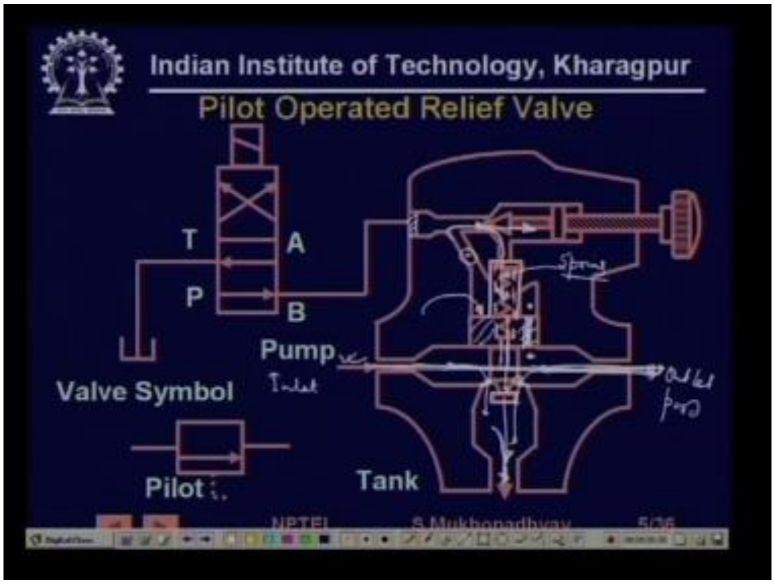

That is a pilot is a pilot is a line from using which by applying pressure from a remote place you can operate a valve, so there may be some normal operation mode of the valve but you may sometimes the operator may like to override that mode and get into a different mode and that you can do sitting in the control room while the valve may be at the field somewhere near the machine so here we have a pilot operated valve see the operation.

So this is the pilot port right suppose first of all we keep it closed, so if you keep it closed suppose it is sealed so normally fluid is flowing through this going out through this or rather opposite it is going yeah it is going through this and not because of this it will actually what happens is that the fluid is flowing through this tank and going out okay now sorry this is yeah actually right t correct so this fluid is going through this like this is the inlet port and this is the outlet port and there is a you see that this is all this is actually Hollow but so and there is a slight hole here slight capillary like opening which is not shown am making it full. So what happens is that the pressure here is generally in the steady state it is the same as a pressure here, so on this pool on this pool the net force is zero.

So but there is a spring this is a spring so the spring is pushing it down so this edge these two edges they are actually pressing against here and closing so there is no leakage to tank directly the fluid is passing this is the normal scenario, now suppose the pressure goes starts going high here so what will happen is that, slowly because of the capillary it will take some time but the pressure here and pressure here.

After some time are maintained because of this opening so the pressure here will also go up, in this way at some time the pressure here will go so high that it will push this puppet on this direction and there will be a leakage flow this is actually a hollow can you see these dotted lines this indicates that it is hollow and there is an opening, so the fluid will start flowing through this hollow and it will flow out to the tank.

So the pressure cannot increase beyond a certain level, now suppose you want to at some points of time due to the operational requirements you want to open this valve.

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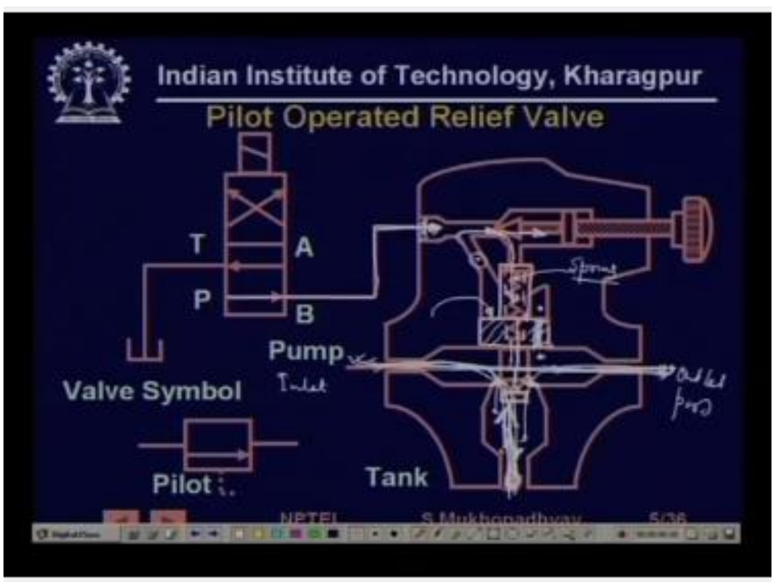

Before that if you if used now if you try to make it flow through this it will not flow because it will close so there cannot be any tank to pump flow, on the other hand if you now apply a pilot pressure here if you apply a pilot pressure here for example you see you can apply pilot pressure using a directional valve, so in this position of the valve pump is connected to B. So in this is so in this position what is going to happen is that.

Because you are applying pressure here so you are pushing this so you are pushing this down so you are pushing this down so the pump can be pump will flow to tank this will flow to time, so you can now have you can buy by applying a certain amount of pressure you can decide the level of pressure at which this will drain to tank. So the relief level can be programmed so such things can be done using pilot operated reading valves.

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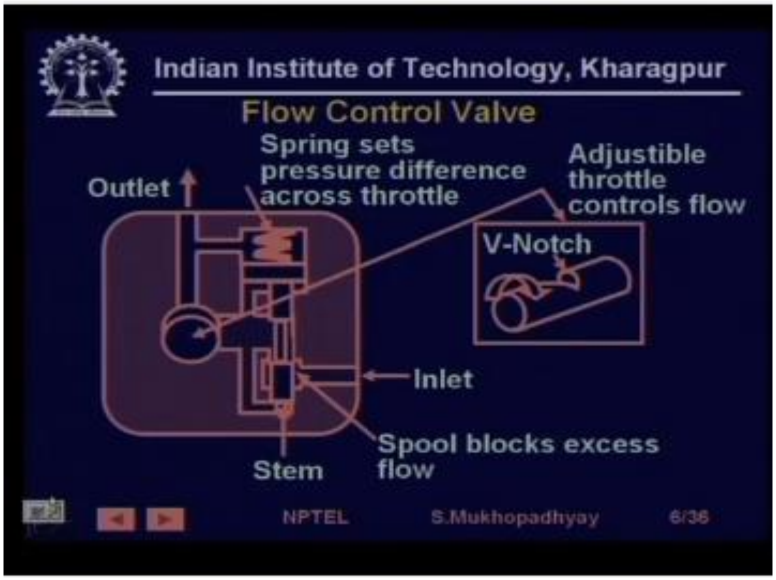

Going over to the next one, flow control valve. These are valves which are made such that the flow across them irrespective of irrespective of the pressure variation irrespective of the pressure variation.

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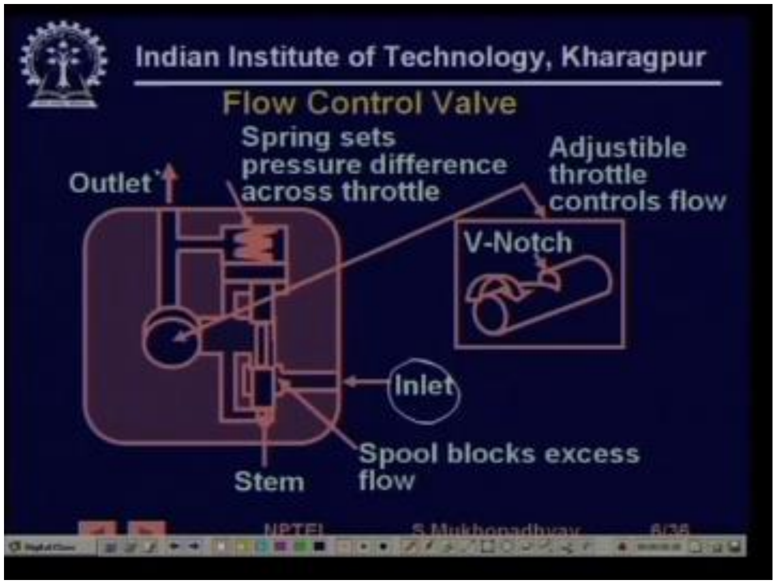

At the inlet the flow through the outlet is going to be constant and this can be adjusted by this there can be different settings of flow and one can adjust that setting, so how is that achieved?

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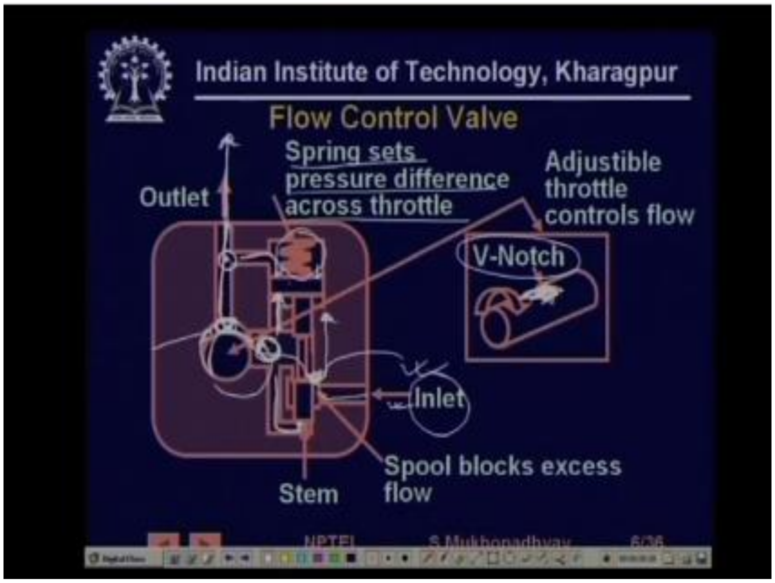

This is achieved basically by the fact that this is the inlet port so what is the fluid path, the fluid path is through this through this through this through this through like this, this is the fluid path okay. So there are two obstructions so one obstruction is this one this one this is actually a cross-sectional view. So the actual thing is like this is it is a it is a cylinder with a notch with a v-shaped notch in the middle.

So you can see that the amount of because the notch is V shaped, so if this is rotated if this is rotated then the ends of the V will come here it will become like this, this Crescent will become like this then the fluid has to flow through this much of opening, right now it is flowing through this much of so actually because the cross-section varies here the cross-section is low, here the cross-section is more, here the cross-section is maximum.

So as you rotate it this cross-sectional area through which this flows can be determined, this is the first thing. so i say flow setting can be adjusted by moving this valve moving this notch now what happens is that suppose the pressure here goes up if it goes up then because it is flowing at a certain across a particular notch there is a particular pressure drop at a particular flow so this pressure will immediately tend to rise here now if the one the pressure rises this will apply a force is this applies a force then no actually what will happen is that if the pressure rises here.

Than first the pressure will rise here now this means that this pressure will act the pressure will also so the flow will tend to because of that the flow will tend to increase here but because the pressure rises here so the flow will this pressure will pressurize it here and here so that this pool will move this side now if this pool moves this side you can understand that this opening will close once this opening closes then there is going to be a greater pressure drop here and naturally since this pressure drop is fixed it has gone up.

But at this level it is fixed then if you increase the pressure drop here then the pressure here will fall so in this way the pressure is going to be adjusted there is going to be this will stay a particular flow will take place when the pressure difference between these two what is the pressure difference between these two why is this in equilibrium because there is an upward pressure here there is a downward pressure here and there is a spring force which is downward so it will so the difference between this pressure and this pressure in any steady state is always going to be equal to the spring.

Therefore the spring sets the pressure difference across the throttle it is set by this free it is always be equal to the spring force and so now so what is going to happen is that at a particular opening of the v-notch if you have the pressure difference fixed and if you have the opening cross section fixed then the flow is going to be fixed so this is the way that so the moment the pressure goes up the this through this pool will adjust.

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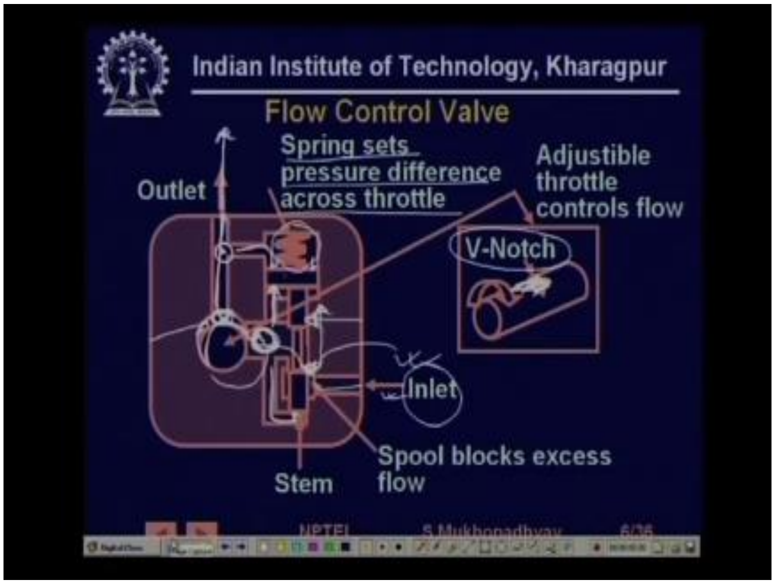

And control the pressure here such that the flow will flow to the load is going to be remain the same so this is the principle of flow control valves.

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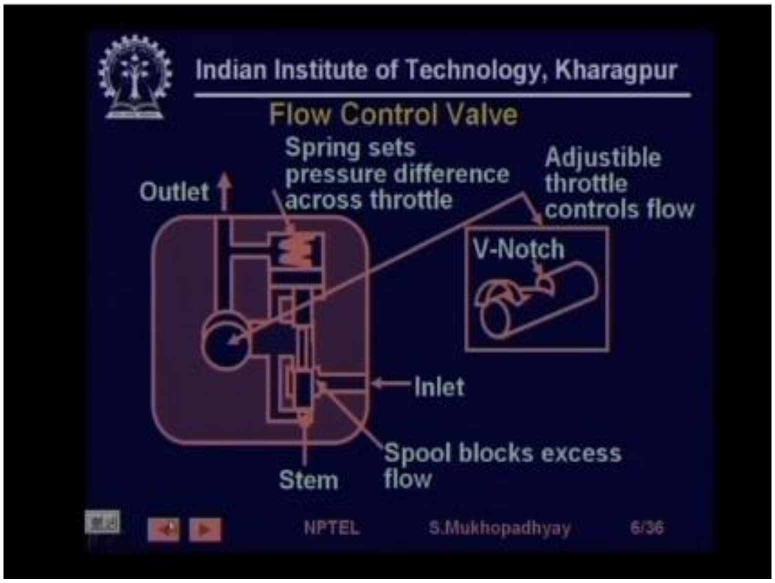

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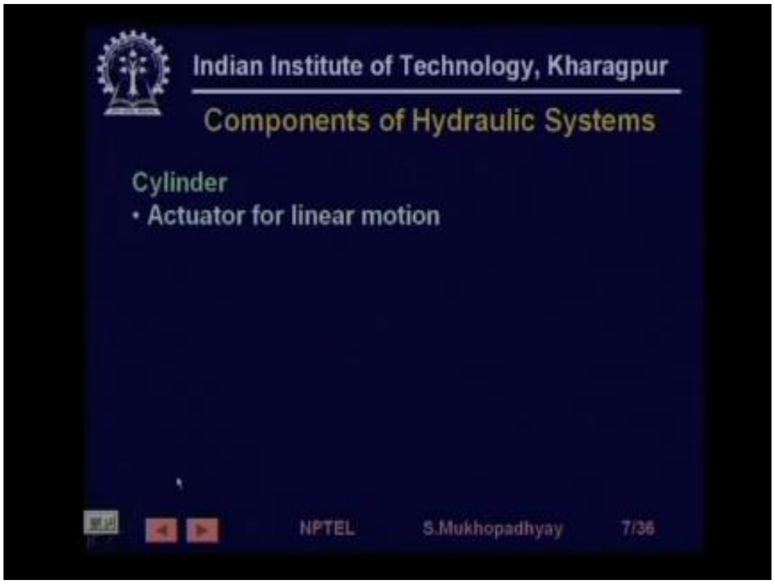

Now we look at so finally so now we have studied a number of valves right so we have first studied pumps and motors which deliver the fluid and finally use the fluid motor is rotary actuator then we have seen how the fluid can be it's directions can be changed and on it's path how flow and pressure can be controlled so now finally that fluid will go to a put to an actuator so what are the actuators can be a rotary actuator is motor which you already studied now we are going to see a linear actuator which is a cylinder.

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So cylinders are generally of two types one type is called single-acting the other type is called double acting so single acting means that it by force it moves only in one direction then it then it generally comes back either by gravity or by spring force etc while double-acting means that by force it can be moved in both directions so for single acting generally the return stroke is not loaded well the forward stroke is loaded while for double acting both strokes can be loaded it is very simple.

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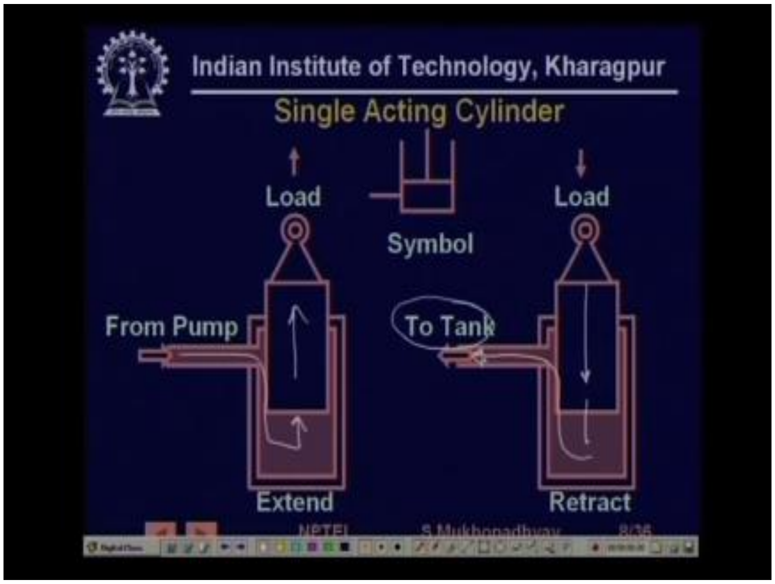

Single acting silly this is at his is a single acting cylinder so if you put some pressure from the pump it will go up it will create a force so it will go up so that is the power stroke going up on the other hand if you connect it to tag in this case it is by gravity so because of the load this is this thing will come up and the fluid will be pushed out to the time so if you want to have the power stroke you to connect it to pump if you want to have the retraction stroke here we have two connected to tank.

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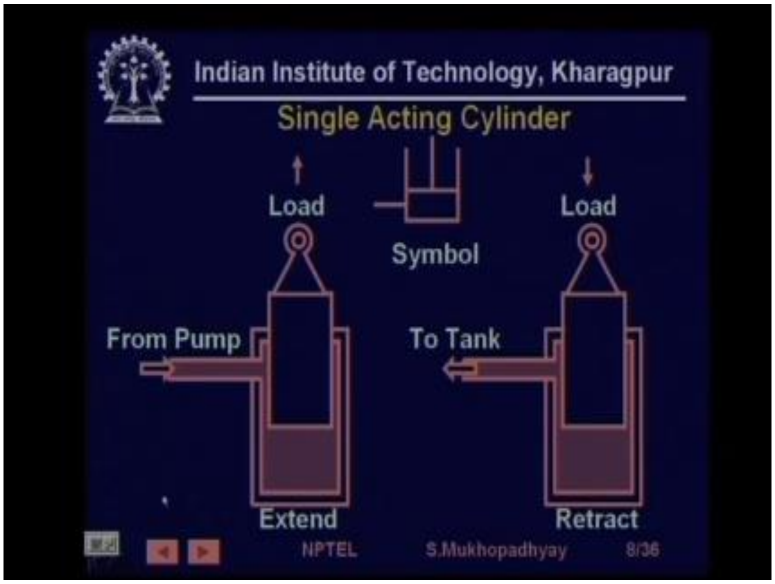

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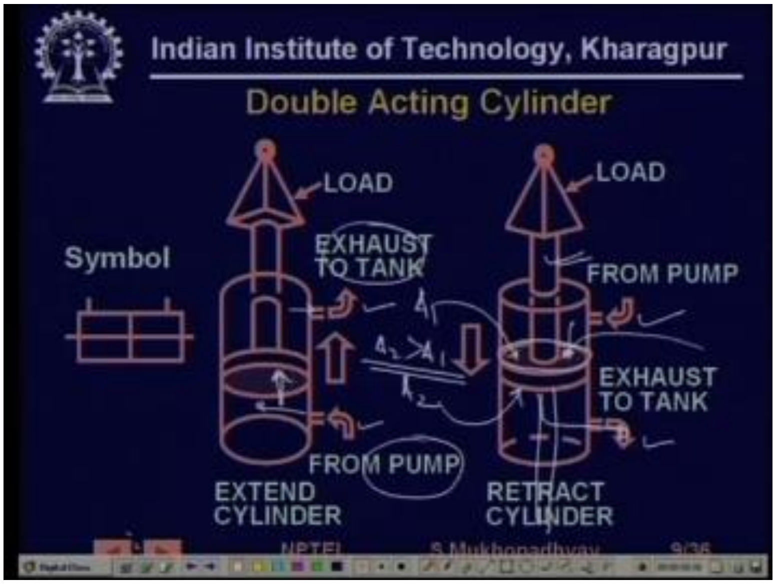

For double acting cylinders are also very simple devices so here you can see that you can do you have two ports one is pump one other is tank. Yeah, actually you have two ports so one of the so if you connect this one to pump and this one to tank then the fluid will enter here and will go out here and will be pushed in this direction. On the other hand if you reverse that if you take this one to pump and this one to tank then fluid will enter here and will go out through this direction.

Only one thing to note is that for the pressure that you will be required to move this that is the, we want to mention that this cross-sectional areas are different on the two sides if you have this called a single rod that is the rod to which the load is connected is connected only on one side. So therefore, this area is going to be less than this area A_1 and A_2, so A_2 is greater than A_1. If you have a double rod cylinder where you have a rod on this side also, then it may be that $A_2 = A_1$ or even A_2 can be less than A_1 so this is a very simple device.

Now, so far we have we have mostly seen apart from pressure control and flow control we have mostly seen valves where the direction of the fluid is changed, so we have seen mainly directional valves. Now we are going to look at some valves where the flow or pressure can be controlled in a continuous or a step less manner, okay.

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So it is, so therefore we use what are known as proportional and servo valves. So you have here what at the, I mean the advantage is that you have a step-less control of position, force, velocity extra,

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And you can drive these are typically electro-hydraulic valve, so that you can drive them accurately using mainly using current, and so that you can sometimes of computing interfaces one of the major areas of application is avionics. So the onboard flight computer will drive these actuators such that the plane can flow can fly.

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So obviously you use hydraulics for high power weight ratio sometimes you can improve the power weight ratio and drive very high loads using multiple stages of hydraulics.

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And they use open, partially open or partially closed and sometimes full closed loop control. So these are generally very precise devices quite expensive difficult to make manufacture and mainly use for moving for precision motion of very high power loads, so we will start with proportional valves.

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So we can have open loop technology where we, when can you use open loop control you can use open loop control when this we have studied in control theory that why do you need feedback, you need feedback when you know that the system model can change and there are lots of unknown disturbances so if you have this sort of situations then you use closed loop feedback control, but in a situation but for closed loop feedback control you need you may need an expensive feedback arrangement.

So if you can sometimes do away with that, if you know that your system is highly stable does not change there is little uncertainty very well characterized and you know the load, so there is not going to be an unexpected kind of load in such a situation you can use open-loop control, and typically in a in a control system there will be multiple loops so you, if you have some of the loops closed and the maybe the final in these are generally used for creating motion so maybe they if the final motion of the final element is not sensed that I call it a partial closed-loop control.

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So proportional valves use this open or partial closed-loop control and they are very highly characterized devices. So basic idea is to create flow or pressure proportional to spool stroke, so basically there it is like a directional valve only thing is that in directional valves when you switch on one side of the solenoid it comes and sticks at one end when you energize the other side of the solenoid it comes and sticks at the other end. Here you are not going to do that here you are going to make continuous motion of the spool and so all these openings are going to open to various extents and their why you are going to control the flow or the pressure so you are basis so basically the structure is the same so by it creates flow or pressure proportional to spool stroke so it is so the flow or pressure will be proportional to the motion of the spool.

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And this will in turn create proportional force or speed at the actuator depending on what the actuator is let us consider a linear actuator at this point of time and as we have seen that in the as you said that in the pilot operated relief valve you can you can control the pressure at which the valve will vent so how do you do that you do that by controlling the pilot pressure how do you control the pilot pressure you can put a proportional valve at the from the pump.

And then connect the outlet of that pump of that valve to the pilot port of the relief valve and then by using computer or using at I mean using manual operation you can control the release pressure.

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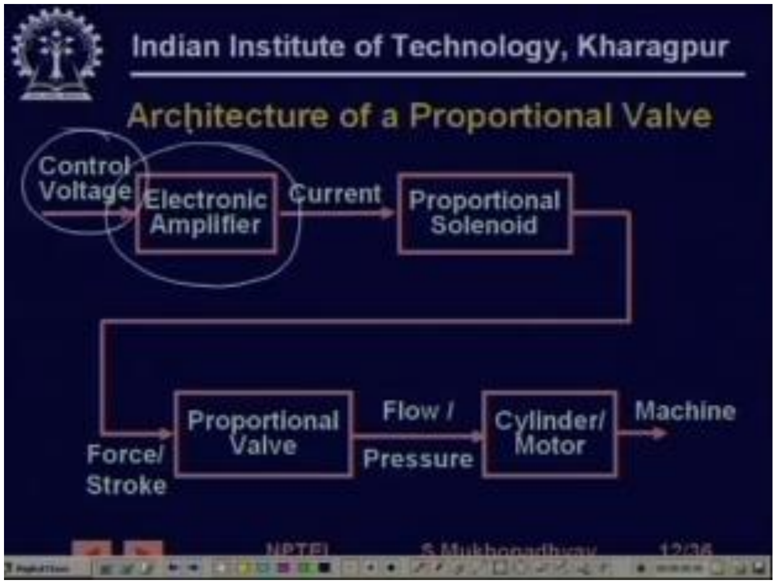

A typical proportional valve will have these elements so it is operated by a control voltage which can be given manually or which can come from a computer then there is usually a set of electronic circuits which do various kinds of things which do filtering which will do amplification which can do sometimes if part of it is digital they will do digital-to-analog conversion and there can get there is a main thing is that it must add some power.

That is there will be a server amplifier and there will be a voltage to current converter so finally from this control voltage.

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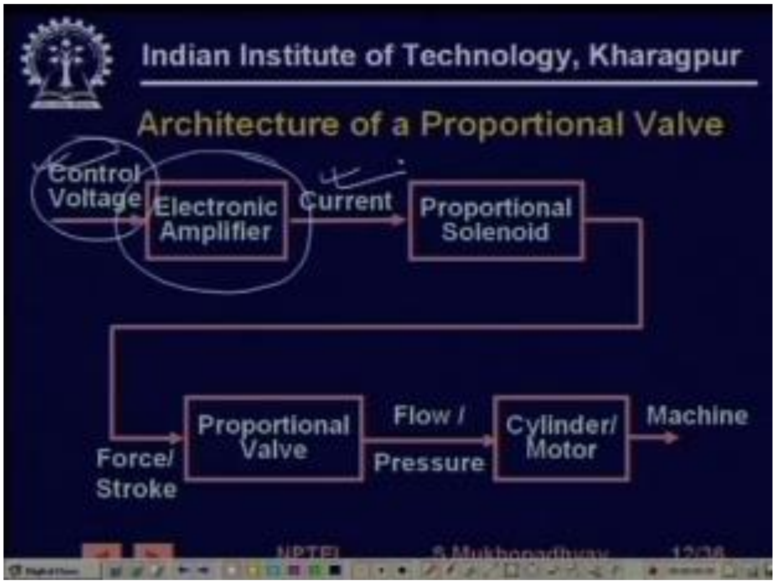

Which does not any power you are going to drive some current this current will be applied to a proportional solenoid so the characteristic of the proportional solenoid is such that at a particular current it can create a particular force so if it can create a particular force.

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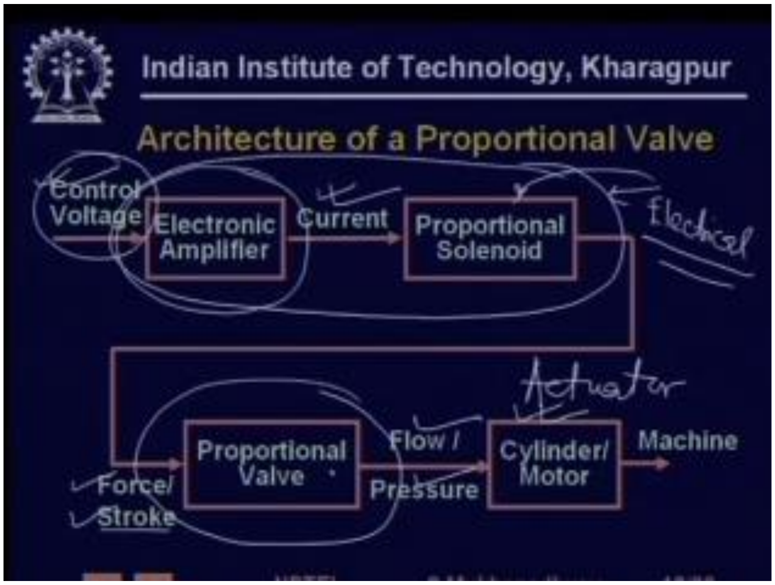

Or all it can create a particular stroke as we shall see the proportional valves can be either force controlled or stroke controlled so if you control the stroke then the Hydra this is the this is the oil part of it this is deserve that is why these are called electro hydraulic so this part is electrical, electrical this is the hydraulics so if you create a force or stroke on the spool you will get a corresponding flower pressure and that flow pressure can be applied to us to that this is actuator finally.

Which is connected to the actual load which you want to move machine so this is the cylinder or the motor so these are the, this is a typical structure of a proportional valve.

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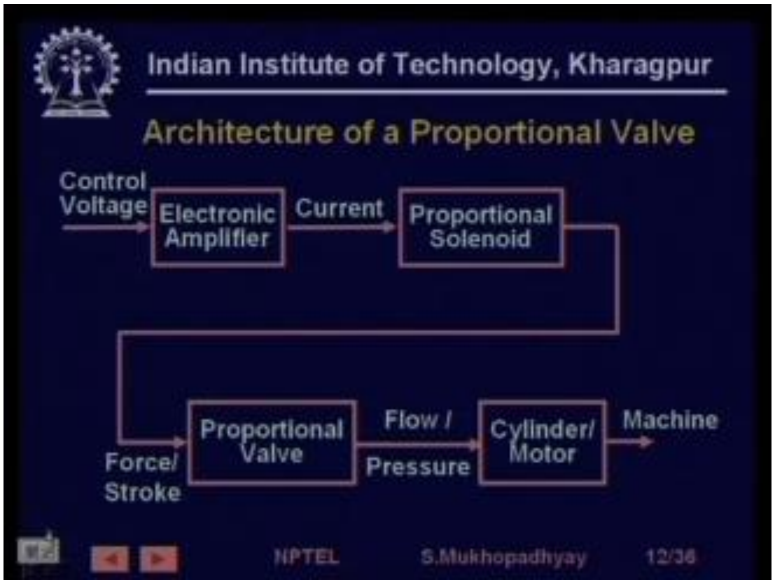

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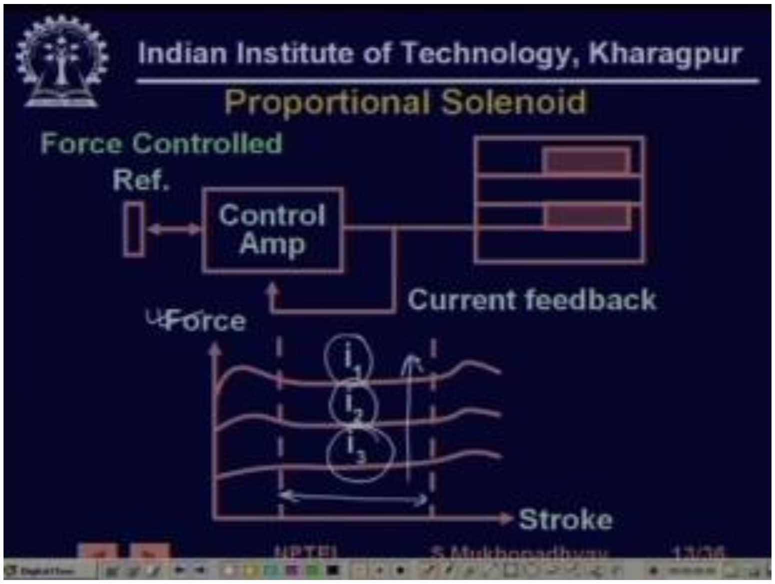

So proportional solenoids are typically made if you want to have a force controlled proportional solenoid ocean and valve then what you do is that you do actually how do you do force control you do current control and you do current control and then you have made the solenoid such that it is this is for stroke characteristic so you see that for a good range of the stroke the force remains constant at a given current.

So by changing the current you can take the force up and it will take it will it will stay constant over a length of the trove in fact it should be mentioned that these valves the stroke length is actually very small it is of the order of millimeters full stroke length so therefore generally the stroke length is not large and therefore the valve is actually expected to operate only in this zone.

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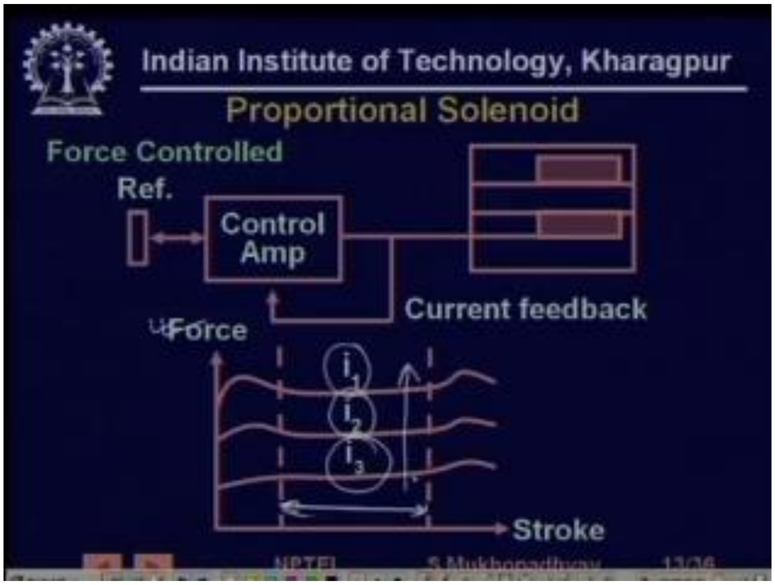

So you have a constant current to force ratio so therefore if you want to have if you want to control the force it is equivalent to control the current.

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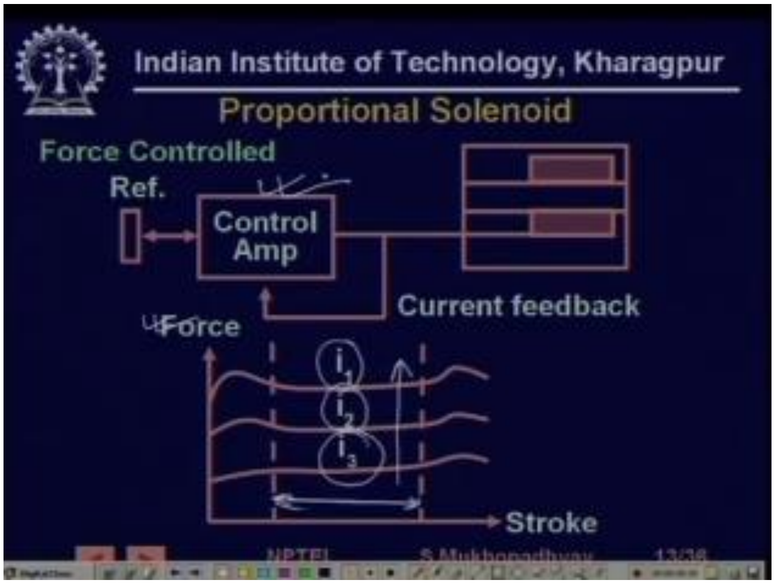

Which is very simple as we have as we will see later also that current feedback is very much preferred because it is very easy to get that feedback for example atypical very cheap Holly fake sensor can give you a very good current feedback sometimes the current sensing resistant you can drive the current through a small resistance and then take the voltage drop that will give you a very good current well. So that brings down the cost if you really wanted to on the other hand.

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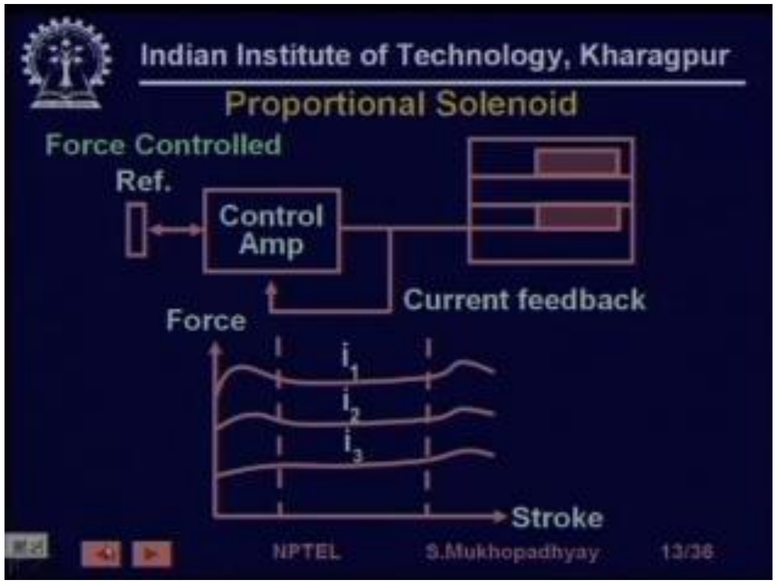

Remember that this force control strategy will is essentially dependent on this force current characteristic of this fall so that must be insured and if it is not good enough then your force is not going to stay constant on the other hand.

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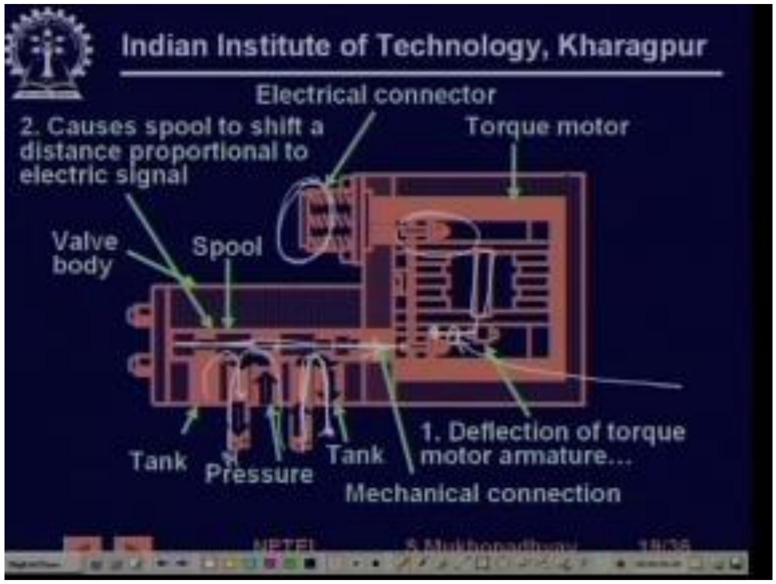

If you have with where you have a stroke control we have not drawn the stroke controlled me just go ahead and kill I on the other hand i ah ok so go back okay so you see that this is a I am sorry yeah so typically typical construction of a force controlled proportional valve so what you are happening is that you see here you are giving the electrical connection that is the servo amplifier current has to be driven here that will this is at this is the torque so called torque motor so what will happen is that it will this is the connector.

So if you drive the current then what will happens is that say this will move this magnet system will pull it and it will tilt slightly so it will push it will push it here once it pushes this is actually connected this is this is actually connected so once this pushes this valve will shift this is the spool you can see the spool this is the spool shaft so once this moves this side this is the pump which gets connected to this port and this is that this port gets connected to the tank.

Okay on the other hand if you connect if you move it this way then this will get connected to this port and this will get connected to this port so this will make the spool shift in this case because of this feedback it will move a certain only a certain distance in the case of so you see that in the case,

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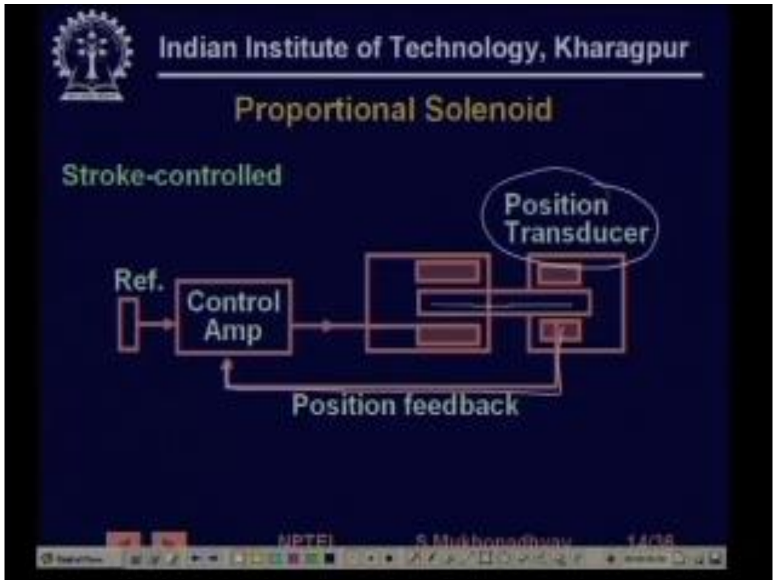

Of force control in the case of stroke controls or annoyed you actually put a position transducer so you actually put a position transducer and see the stroke and you give feedback in that case you can see that this characteristic of the because of the feedback system so therefore the characteristic of the valve will not be very closely controlled but the position transducer accuracy is very important and the characteristic of the overall proportional solenoid is going to be still going to be fairly constant.

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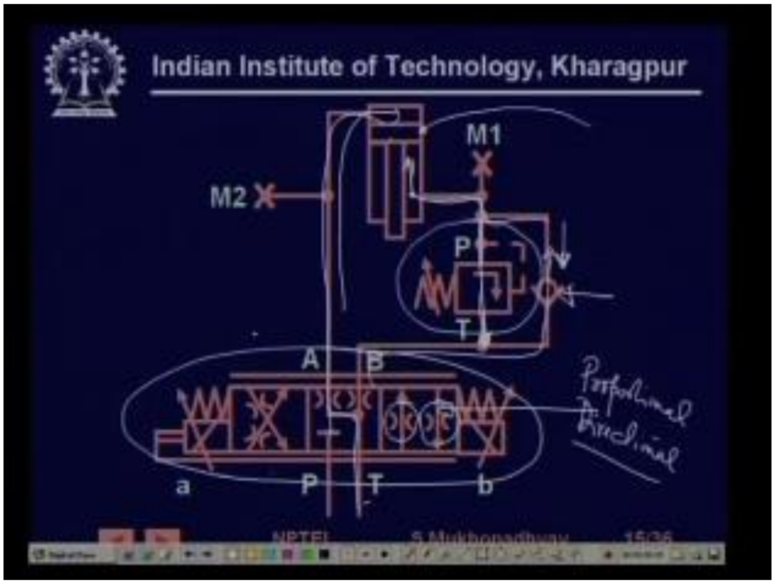

So now so this is you know this is atypical application circuit what we are trying to do is this is a this is a single acting cylinder so you can see that if it is in this position then the then the cylinder is locked you can see that this is a cylinder so the cylinder’s locked why the cylinder is locked the cylinder is locked because of this relief valve see this is a check valve so flow cannot take place from this place to this place if flow has to take place through this path then a certain pressure difference is required so unless the weight so the cylinder cannot come back by its own weight because the fluid cannot go out of this chamber.

So if you put it in the central position of this four-way valve3-position four-way valve then the cylinder is locked and it does not slowly come down because of its own weight on the other hand if you connect it to this position this means that these symbols mean that this is that these are proportional directional valves so it is not only that the is not only that the position of the valves can be shifted to one of the three as is commonly known in directional valves the flow rate or can also be changed by using proportional control.

So the rest is simple if you connected this place the fluid will flow into this and will flow through the valve on the other hand if you connect it to this position then the fluid will flow through this to the check valve and go to this and come back to the time to the time so this is so you see that here you by using this proportional directional valve using only one element you are able to not only control the direction but also control this velocity or the speed by using the proportional valve that is sometimes an advantage.