Industrial Automation & Control
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Lecture - 27
Hydraulic Control Systems – II

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Welcome to lesson 27 of industrial automation and control. 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 instructional objectives.

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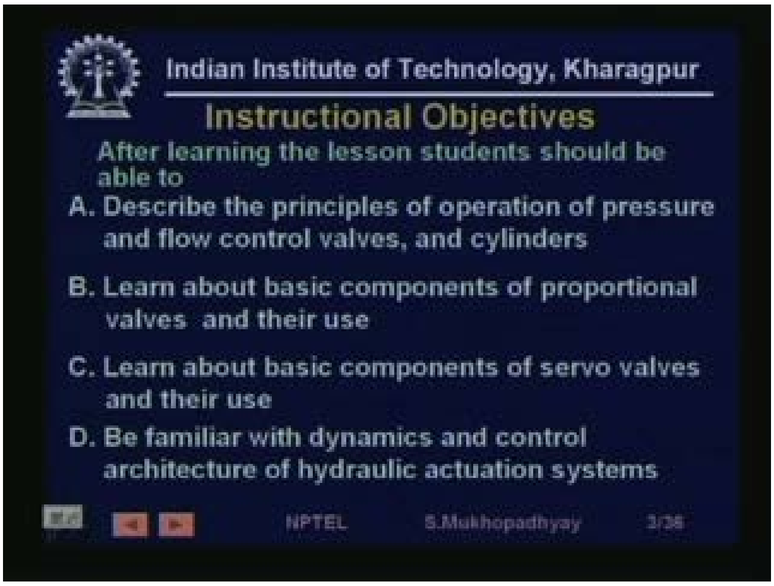

Describe the principles of operations of pressure and flow control valves and cylinders, basic components of proportional valves, learn about basic components of servo valves and be familiar with the typical, you know control architecture of hydraulic actuation systems, these are the instructional objectives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

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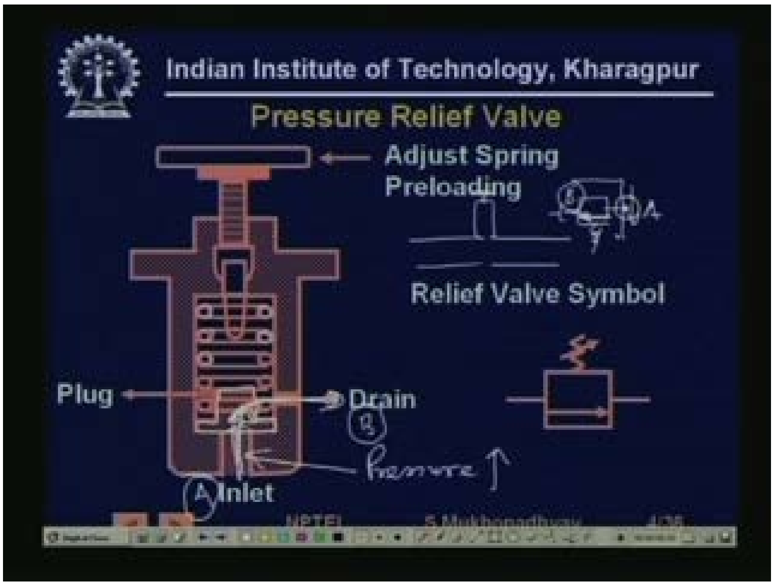

So, coming over from the last lesson, pressure relief valves, these are, these valves are typically mounted, so you have, these are not valves where these are connected in parallel, in general. That is you have a pipe through which the main flow takes place and this valve is going to be connected in parallel, 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 fluids 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. So, if the pressure goes high here, this is a simply a ((Refer Time: 03:10)) poppet like thing this one, which is loaded by the 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 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 the pressure relief valve. Now, sometimes you need to operate this relief valves in various modes using a pilot, that is, a pilot is a line from using which by applying pressure from a remote place, you can operate a valve.

So, the there may be some normal operation mode of the valve, but you may sometimes, the operator may like to overwrite that mode and get into a different mode, and that he can do sitting in the control room while the valve may be at the field somewhere near the machine.

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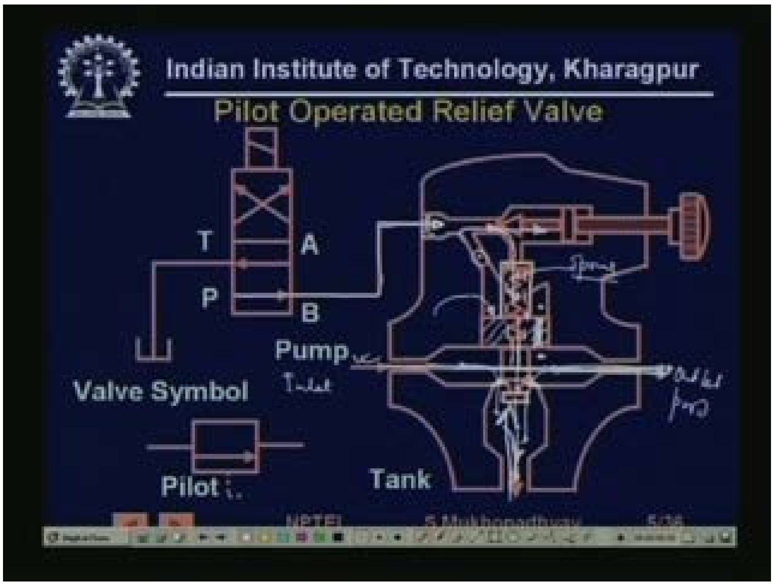

So, here we have a pilot operated valves, see the operation, so this is the pilot port right, suppose first of all we keep it closed, so if we keep it closed, supposed it is sealed. So, normally fluid is flowing through this, going out through this or rather opposite, it is going , it is going through this and because of this, it will actually what happens is that, the fluid is flowing through this tank and going out. So, this fluid is going through this like this, this is the inlet port and this is the outlet port.

And there is a, you see that this is actually hollow but and there is a slight hole here, slight capillary like opening, which is not shown I am making it full. So, what happens is, that the pressure here, is generally in the steady state, it is the same as the pressure here, so on this spool, 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 pressuring 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 detection time, that the pressure here and pressure here after sometime are maintained because of this opening. So, the pressure here will also go up, in this way at sometime the pressure here will go so high, that it will push this poppet on this direction and there will be a leakage flow.

This is actually a hollow, can you see this 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, before that, if you 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, this is, so in this position what will, what is going to happen is that, because you are applying pressure here, so you are pushing this. So, the pump can be, pump will flow to tank, this will flow to tank, so you can now has, you can, by applying a sudden 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 relief valves, going over to the next one.

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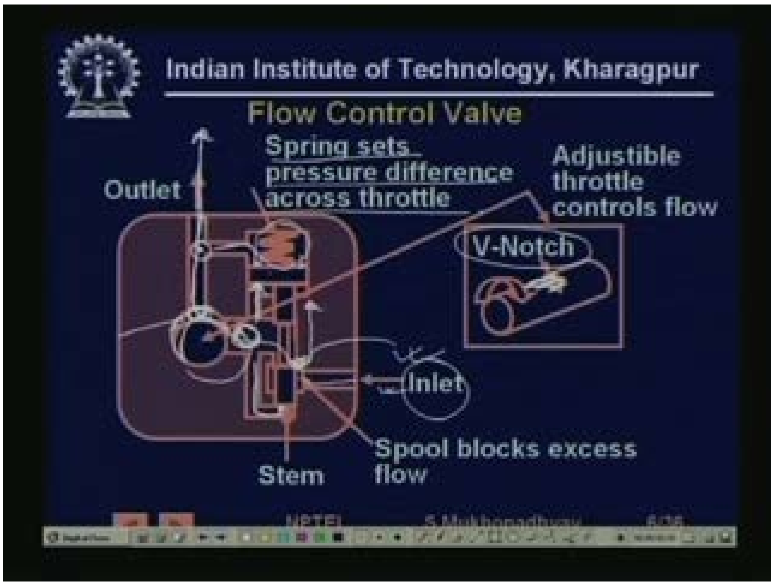

Flow control valves, these are valves which are made such that, the flow across them, irrespective of the pressure variation at the inlet, the flow through the outlet is going to be constant and this can be adjusted by, this I mean there can be different settings of flow and one can adjust that setting. So, how is that achieved, 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 a fluid path.

So, there are two obstructions, one obstruction is this one, this one, this is actually a cross sectional view, so the actual thing is like this, it is a cylinder with a notch, with a 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, then the ends of the V will come here, it will become like this, this crescent become like this.

Then, the fluid as 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 a first thing, so the 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, in the when the pressure rises, this will apply a force, if this applies a force then, no. Actually what will happen is that, if the pressure rises here, then the, then first the pressure will rise here, now this means that, this pressure will act, the pressure will also, so the, 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 spool will move this side, now if this spool move this side, you can understand that this opening will close, once this opening closes, then there will there is going to be a greater pressure drop here and naturally, since this pressure drop is fixed latter it 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 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 spring, it is always be equal to the spring force.

And so now, so what is going to happen, is there at a particular opening of the V-notch, you see how 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 that pressure goes up, the this thread ((Refer Time: 13:08)) this spool will adjust 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.

Now, we look at, so finally, 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 as a rotary actuator. Then, we have seen how the fluid can be, it is directions can be changed and on it is path, how flow and pressure can be control, so now, finally that fluid will go to a, go to an actuator, so one of the actuators can be a rotary actuator in motor which you have already studied.

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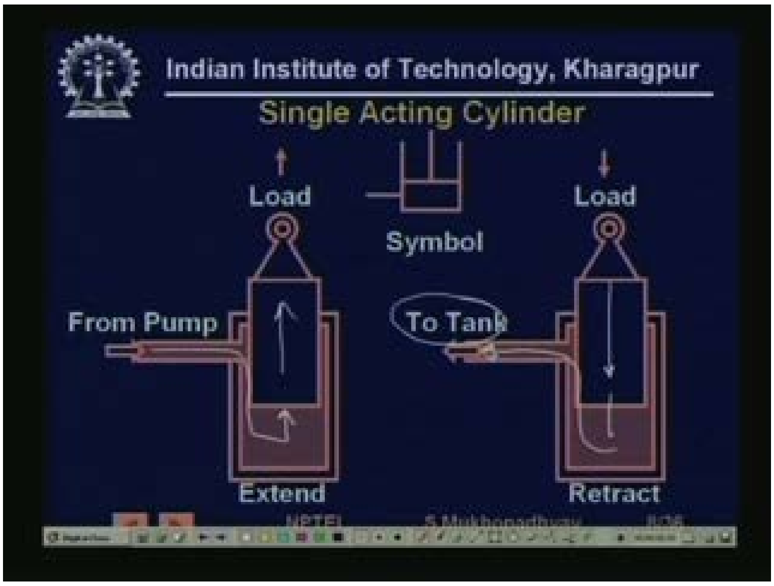

Now, we are going to see a linear actuator which is a cylinder, so cylinders are generally of two types, one type is called single acting, the other type is call double acting. So, single acting means that it, by force it moves only in one direction, then it generally comes back either by gravity or by spring force etcetera. 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, while the forward stroke is loaded, while for double acting both strokes can be loaded.

It is very simple, single acting cylinder, this is a single acting cylinder, so if you put some pressure from the pump it will go up, it will create a force and it will go up, so that is the power stroke going up. On the other hand, if you connect it to tank, in this case it is by gravity, so because of the load this thing will come up and the fluid will be pushed out to the tank. So, if you want to have the power stroke, you have to connect it to pump, if you want to have the retraction stroke, you have to connect it to tank.

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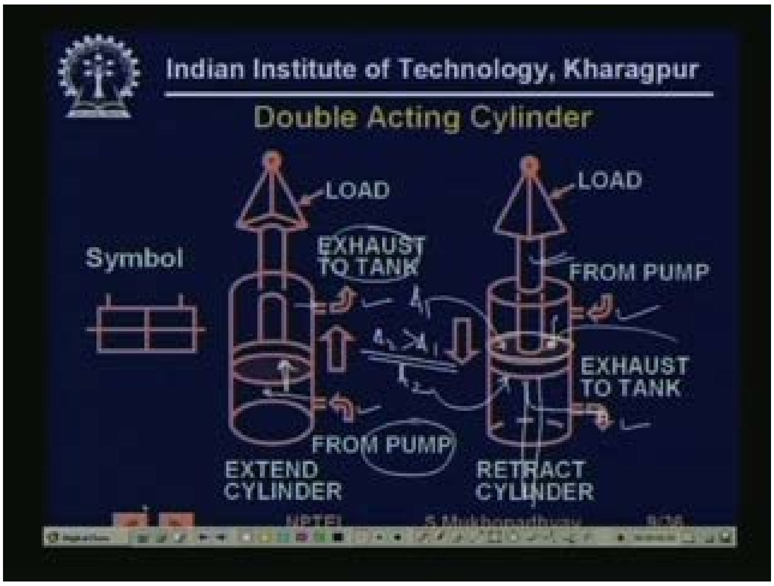

For double acting cylinders are also very simple devices, so here you can see that you can, these have two ports, one is pump, one other is tank. Actually, you have two ports, so one, so if you connect this one to pump and this one to tank, then the fluid will enter here and will go out here and we will 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 notice that, the 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 is 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 is equal to A 1 or even A 2 can be less than A 1, ((Refer Time: 16:27)) so this is a very simple device. Now, so far we have mostly seen apart from pressure control and flow control we have mostly seen valves, where the direction of the fluid is changed, 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.

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So, it is, so therefore we use, what are known as proportional and servo valves, so you have here, what the I mean, the advantages are that you have a step-less control of position, force, velocity etcetera and you can drive this, these are typically electrohydraulic valves, so that you can drive them accurately using, mainly using current and so that you can sometimes have 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, 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 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, 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 control system, there may be multiple loops. So, you, if you have some of the loops closed and the, may be the final, these are generally used for creating motions.

So, maybe the, if the final motion of the final element is not sensed, then I call it a partial closed loop control, 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 is a, it is, it is like a directional valve only. Only thing is that, in the 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 this spool and so all these openings, are going to open to various extends and thereby, you are going to control the flow or the pressure. So, you are, so basically the structure is the same, so by creates flow or pressure proportional to spool stroke, so it is, so the flow or pressure will be proportional to the motion of this spool 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 we said that in the pilot operated relief valve, 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, I mean using manual operation you can control the relief pressure.

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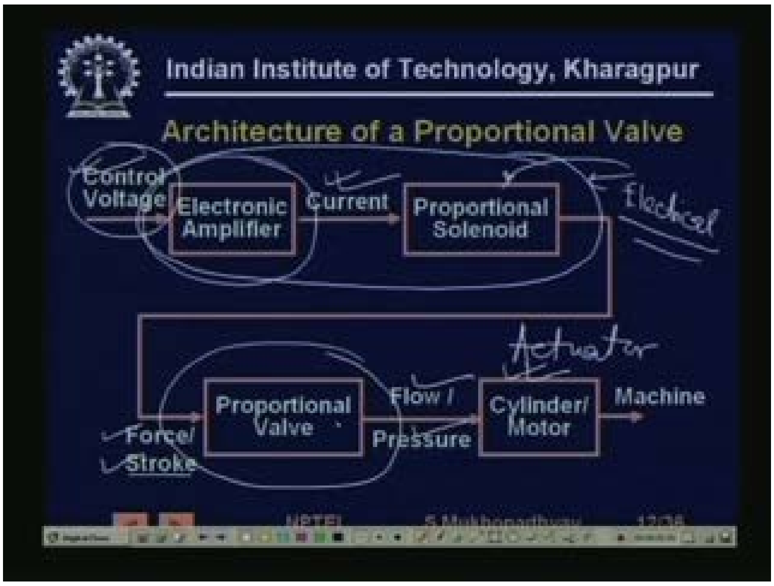

A typical proportional valve will have these elements, so it is operated by a control voltage, which can be given manually or which can come from a computer. Then, there is usually a set of electronic circuits, which do various kinds of things, which do filtering, which will do amplification, which can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

That is, there will be a servo amplifier and there will be a voltage to current convertor, so finally, from this control voltage which does not have any power, you are going to drive some current. This current will be applied to the proportional solenoid, so the characteristics of the proportional solenoid is such that at a particular current it can create a particular force. So, if it can create, say create a particular force or 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, this is the coil part of it, these are, that is why these are electro hydraulics, so this part is electrical, this is the hydraulics. So, if you create a force or stroke on this spool, you will get a corresponding flow or pressure and that flow or pressure can be applied to as through the, 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, these are typical structure of a proportional valve.

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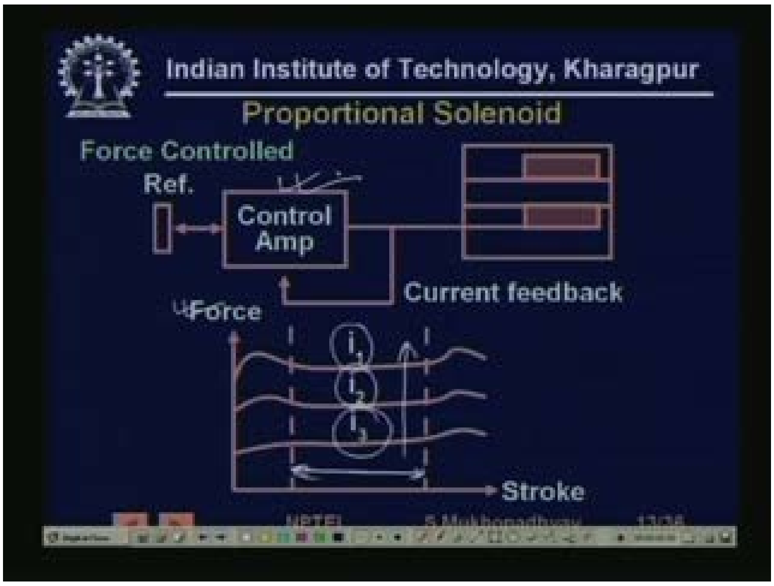

So, proportional solenoids are typically made, if you want to have a force controlled proportional solenoid, proportional valve, then what you do is, that you do actually how do you force control, you do current control and you do current control and then you have made the solenoids, such that it is, this is the force 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 stay constant over a length of the stroke.

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, 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, 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, a typical very cheap hall effect sensor can give you a very good current feedback, sometimes a current sensing resistant, you can drive the current through a small resistance and then take the voltage drop, that will give you very good current value, so that brings down the cost, if you really wanted to. On the other hand, remember that this force control strategy will is, essentially dependent on this force current characteristic of this valve. So, that must be ensured and if it is not good enough, then your force is going to stay constant. On the other hand, if you have where you have a stroke control, we have not drawn the stroke control.

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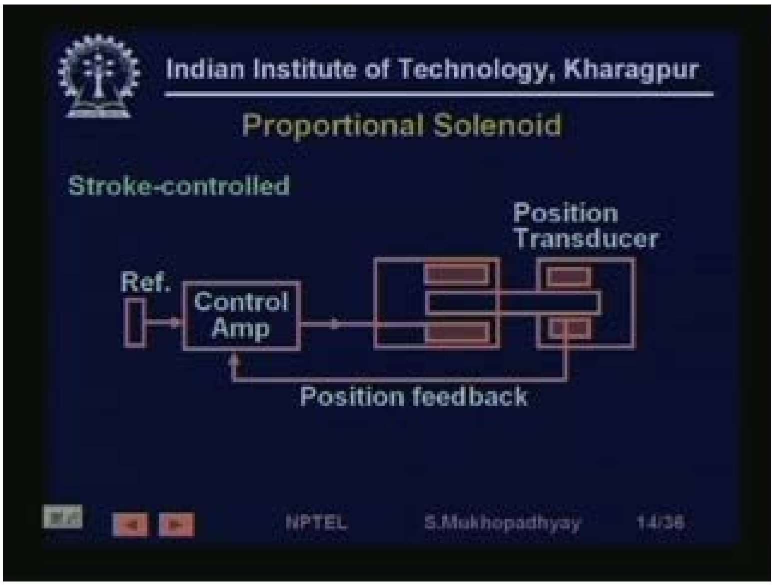

Let we just go ahead and actually I, on the other hand so go back.

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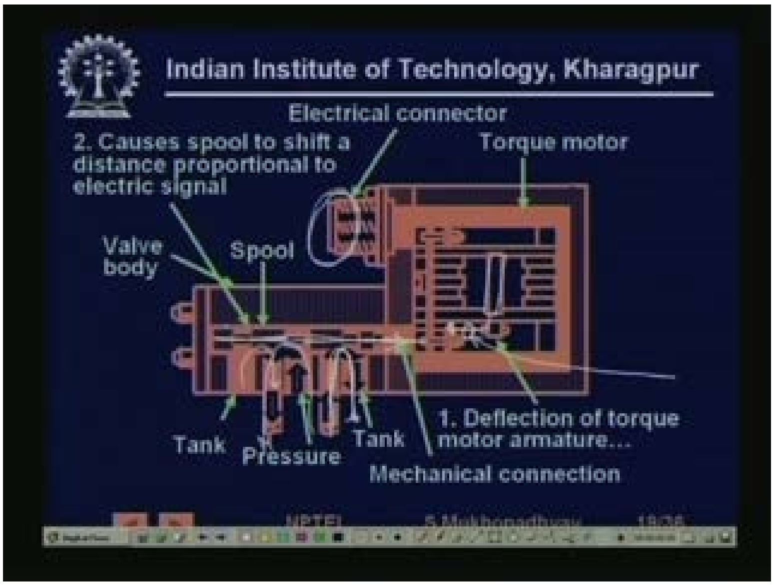

So, you see that, this is a, ((Refer Time: 25:51)) I am sorry, so typically, typical construction of a force controlled proportional valve. So, what here happening is that you see that, here you are giving the electrical connection, that is a servo amplifier current has to be driven here, that will vary, this is a 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 happen is that, say this will move this magnet system will pull it and it will tilt slight.

So, it will push it here, once it pushes this is actually connected, so once this pushes, this valve will shift, this is a spool, you can see this spool this is spool shaft. So, once this moves this side, this is a pump which gets connected to this port and this is the, this port get connected to the tank. 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 of force controlled, in the case of stroke control solenoids 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 it is a feedback system, so therefore, the characteristic of the valve need 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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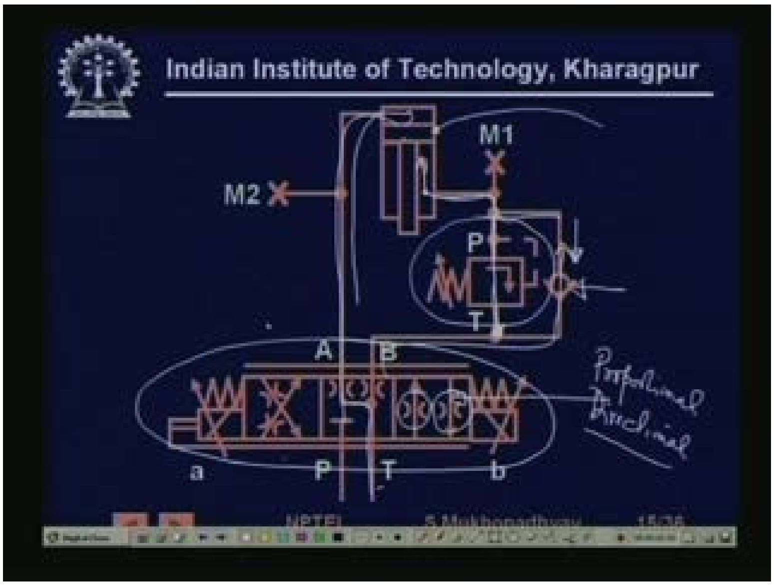

So now, so this is a you know, this is a typical application circuit, what we are trying to do is, this is a single acting cylinder, so you can see that, if it is in this position then the cylinder is locked, you can see that this is the cylinder, so the cylinder is locked, why the cylinder is locked, the cylinder is locked because of this relief valve. See this is the check valve, so flow cannot take place from this place to this place, if flow has to take place through this path, then a sudden pressure difference is required.

So, unless the weight, so the cylinder cannot come back by it is own weight, because the fluid cannot go out of this chamber. So, if you put it in the central position of this four way valve, three position four way valve, then the cylinder is locked and it does not slowly come down because of it is 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, position of the valve can be shifted to one of the three, as this 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 connect it to 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, through the check valve and go to this and come back to the tank.

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.

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Now, let us come to servo valves, they are they were typically developed for aviation applications, because in aviation you have to make very precise movement of this control surface of the aircraft, against very heavy load which is aerodynamic, because the aircraft is moving at huge speed through the atmosphere. So, very precise motion has to be created against high load, it is for these purposes that these servo valves are originally developed.

It is a total closed loop control technology, because you do not want the characteristic to change, everything is very tuned and well, you have all the previous advantages likely electric drive, accuracy, computing interface, flexibility, programmability and hydraulics for high power weight ratio.

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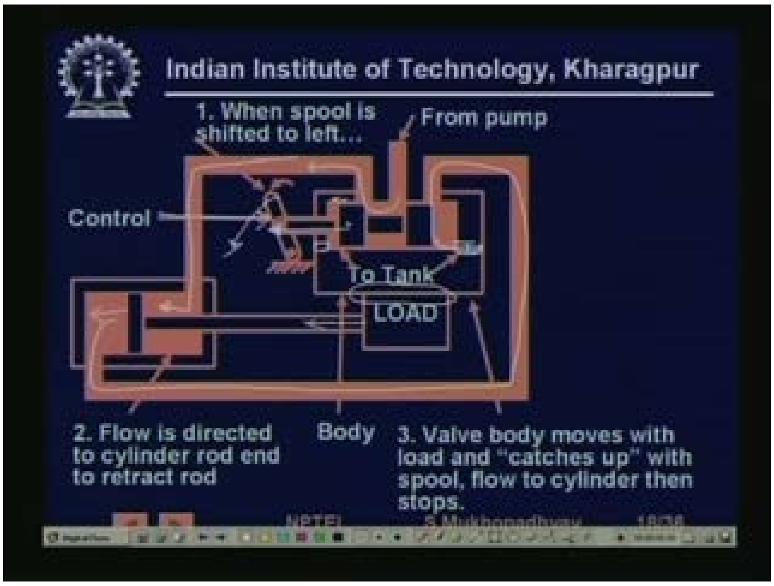

So, what is the basic idea, see a very typical, a very simple type of servo valve, so what is happening here is that, suppose you shift this rod, so if you pull this lever it will move this way, as it moves this way what is going to happen, that this port will be connected to this and the tanks at the end, actually you can imagine that the tanks are here. So, the return stroke is going to be controlled, going to the tank, this is the way the fluid will flow.

Now, interesting thing is where is the feedback, interesting thing is the, that the load is connected to the body, so if you have pulled it pull the spool this side, the cylinder will move which side, it move this side, so the load will also move this side and the load is connected to the body, so now, the body will also move this side, this body, the not the spool, the spool is connected to the lever and the body is connected to the load, so the body will move.

So, the movement of the body is actually like a relatively, like a movement of the spool in the other direction, because the flow, the opening is actually by relative motion. So, if the body also moves in this direction, again this flow this valve will close, so you see, there are, there the particular position of the piston or a position of the load, this flow will again close. Till it closes, there is going to be flow and there is going to be velocity and this load will keep moving this way.

So, if you move lever, the valve is going to move in one direction, then finally come and stop, that is by feedback, so this is the typical you know, very simple, mechanical arrangement servo valve right.

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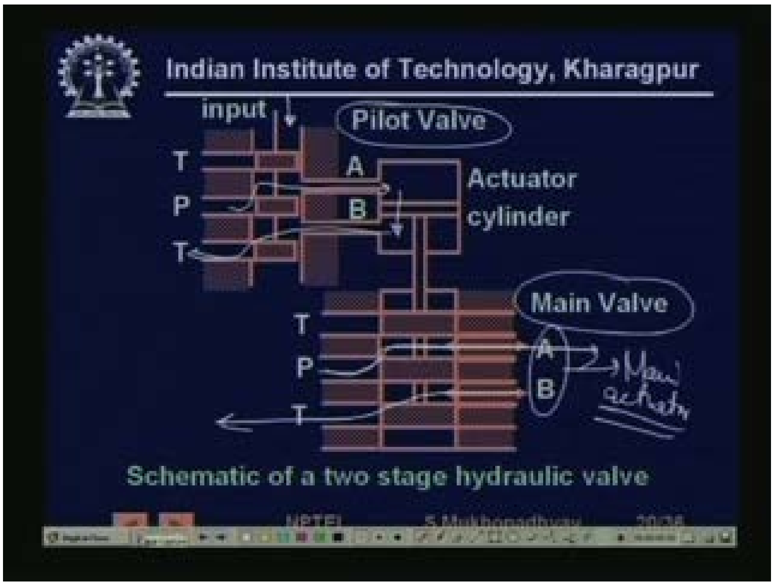

There are various types of servo valve, for example, you one may have a two stage valve right. So, what happens in a two stage valve, in a two stage, because you are you want to control huge power, so the final stage valve is actually very large, so even to move it spool you need another servo valve. So, you see, what is happening you need an actuator, so this is the first stage, so you give actually your control input here, so accordingly if you move it, if you push it this way, then this port will open and this port will open.

So, the cylinder will move down, when it moves down then, what is going to happen is that, this will get connected to this and this will get connected to this, so this is a main valve, this is the pilot valve, that is it is a valve which drives another valve just like you know a pilot rides in front of a car that is a pilot car. So, the pilot is actually the leader which would drives, so in this way, this is the driving valve and this is the driven valve. And this in turn, this ports may be connected, these two ports A and B may be will be connected to the main actuator, which may be a very heavy load, right. So, this way you get power amplification.

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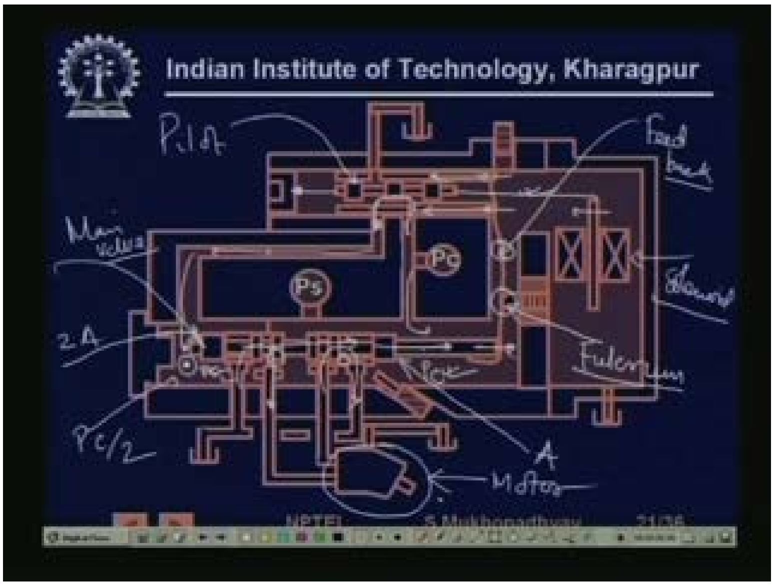

So, here is a typical type of two stage servo valve constructions, see what is happening, you have two kinds of pressure, note first. So, first of all you have, where is the main valve and where is the pilot valve, so this is the pilot valve and this is the main valve, this is the first thing to note, who moves the pilot valve this solenoid, actually this is connected to the spool, it is not shown, so let us identify the parts right and so what happens is that, suppose you tilt the solenoid, something like a torque motor arrangements which we will see what it is.

This will push this valve this way, now you see that there is a control pressure, so the control pressure will come and this valve will move to this end. So, the pressure will fall here, come here and come here and come here and create a pressure here, so you see that, here what is the pressure, here the pressure is P C, but here the pressure is not P C, because it has to drop through this valve, so this is going to be less than PC. In fact, so then, if this side is P C and if there is and if this side is less than P C, and still this has to move this way, then the net force here has to be more than the net force here.

Therefore, the areas must be controlled, so the area here is actually twice A and the area here is A, so the, so for moving this pressure is only required to be P C by 2, the pressure here is only required to be P C by 2. So, the moment this rises above P C by 2, this valve will shift this way, now when this valve will shift this way, you see that this is the final actuator, this is the motor. So, then when this valve will move this way, then what will happen is that probably, this port will get connected to here and this port will connected to here.

So, then you will get pump and tank connected to the motor, now where is the feedback, the feedback is here in this thing, this is the feedback element. So, this spool is going to push this thing this way, when it pushes here is a fulcrum, see fulcrum, so this will again push the spool not the spool, the sleeve, so the spool is being pushed by this one and the this one, this feedback element pushes the sleeves, so it will going to push the sleeves this way.

So, again the relative motion, the this motion of the sleeve, will nullify the relative motion of the spool which was created by the current. So, again at a sudden position, at a sudden at a certain gap, again this will become P C by 2, so now the, when the moment it becomes P C by 2, there is no force on this and it will come to stop. So, it is at that position, that now when it comes to stop, then there is certain amount of opening here and depending on that the… So, when you have a certain amount of opening here, certain amount of flow here, you have certain amount of pressure here, so you are going to drive the motor, at that flow rate, at that speed, so this is the operation of the two stage servo valve.

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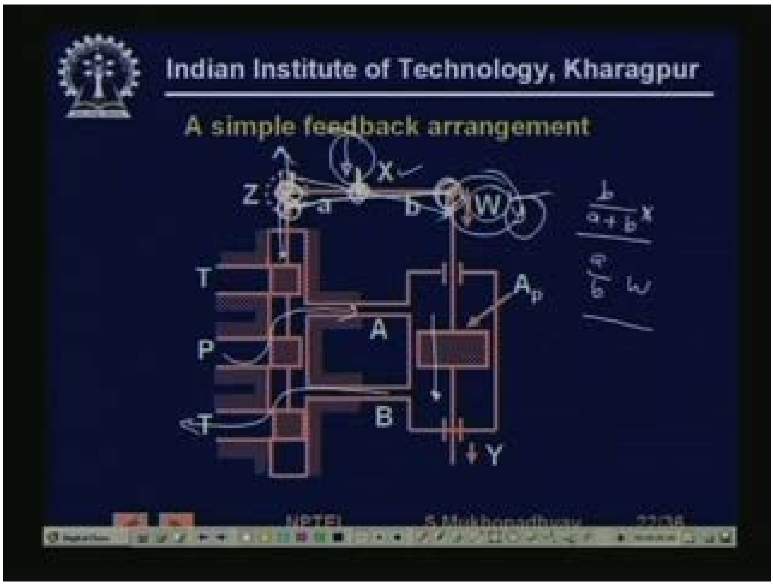

This shows that, this shows this is a slight little analysis of that feedback arrangement that is, if the, suppose you have this is a valve and this is an actuator and there is a connecting link. So, you give an input motion here what will happen, this will initially shift this way, the moment this shift this way, what happens is that the pump connects to this and the tank connects to this. So, the actuator moves this way, when the actuator moves this way, the W moves this way and that will tend to keep it put it up.

So, it, so the cause that was created, the effect will nullify the cause, that is why it is a negative feedback situation and it is stable. So, if you want to analyze the motion of this Z, which finally creates the flow then you have to understand that, then you have to look at it like this. So, you see that first, when you imagine that first, there are actually two inputs and this is the motion that you want to analyze, so first of all you apply superposition, so first of all you apply, assume that W is zero and X is applied.

So, then the this rod is going to move about this, because W is zero, so as pivoted to this that will create some motion. Next you imagine that, X is fixed and W is moving, so now you imagine that it is moving like this, about X, so this is, so if you can, for small motions you can imagine that these two motions are the motions which will be created and the net motion is going to be a resultant of that, so now you can understand.

So, if W is a fulcrum and if X is applied, if an amount X is applied then what is going to be motion here right. So, that is going to be B by A plus B into X. On the other hand if you apply, fix it here and apply a motion Y here, this is Y then, what is going to be the motion here, it is going to A by B into W ((Refer Time: 42:54)) suppose W is a motion here, so finally you get, so what is a final motion Z.

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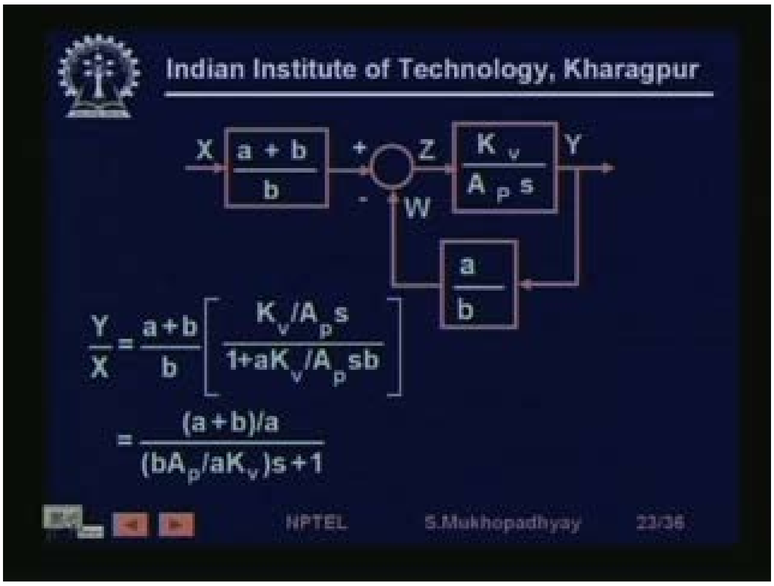

So, you have an effective feedback arrangement where, what is coming this is the motion created by the motion X, this is the motion created by the feedback W and this is the net motion Z, at any point of time and that is going to create, so motion creates a flow and this is a flow again. So, that is going to create a volumetric flow, that divided by A P will give you the linear motion, A P is the area of the piston, that integrated 1 by S will give you the motion of the plane W.

So, this is the control system, that is effective and here is a transfer function, so the transfer function between, you can see that, now that the transfer function between Y by X is actually, in the steady state S is going to go to zero, so it is going to be a plus b by A and it will act like a first order transfer function. So, this is the basic dynamics of any feedback of, you have seen various kinds of, you know linkage type of feedback arrangements. So, this is a basic analysis of one such feedback arrangement and in a typical case such analysis can be made.

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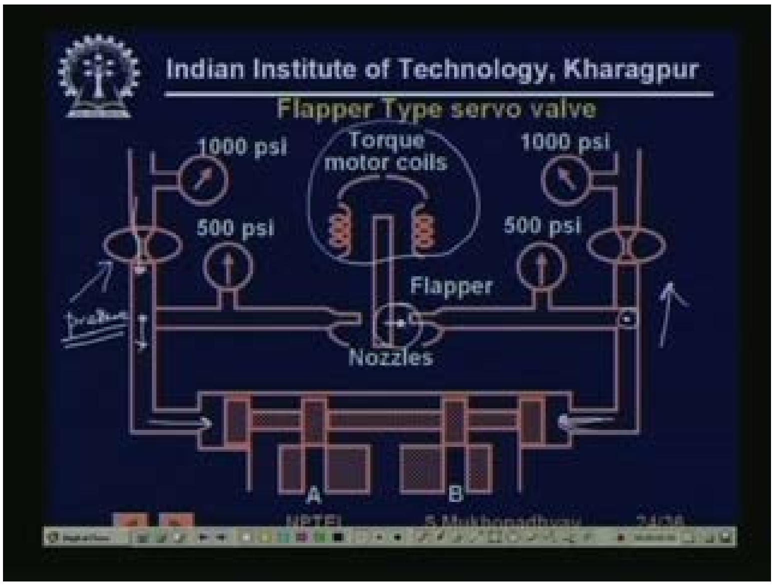

Next we see another type of servo valve, which is a flapper type servo valve, so you see what is happening here, what is happening here is that, again here the, this is the valve, the valve is being moved by applying pressure here or pressure here. So, you have to create a differential pressure, how do you create that pressure as such, this is also this is 100 psi, this is a you know restrictor, so it is a pressure reducing valve, so simply a series obstruction.

So, the pressure will, while flowing the pressure will drop here and it will be something like 500 psi at this two ends. When the this is the flapper nozzle, so when, if the if there is a miniscule motion of this flapper then the pressure at this point is going to rise, if it is this side and the pressure at this side is going to fall. So that will create a differential pressure and it will move this spool, this is the basic principle and how do you create this motion, you create this motion by what is known as the torque motor coil. So, you have a, what sometimes called is called a torquer or sometimes called a torque motor, which can create a miniscule motion of this flapper. The advantages of flapper nozzle is that their gain is very high, that is a very small motion can create a very high pressure difference, so that is, so they are very sensitive devices.

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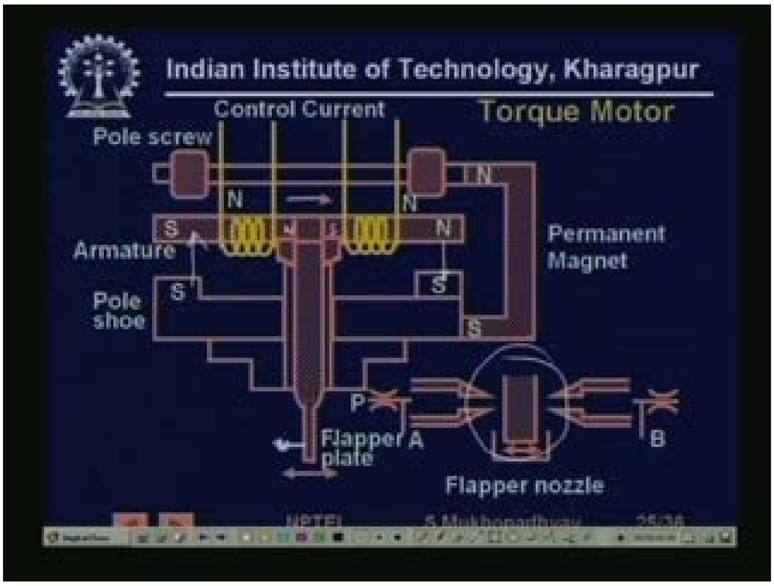

The next is a, so you here you, get to see the construction of the torque, so you see, that this is the construction of the torque, so when what happens is that, you create an S pole here and an N pole here and N pole here is pulled, that is the way it is wound. So, and so what happens is that, now you have this pole shoe, so if you send currents like this, then this is going to repel and this is going to attract. So, this torquer will slightly tilt, it will slightly tilt and is this tilt which will be, this is connected, this is the flapper plate. So, this is the way you control the flapper.

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This is a picture you know Moog is a very, is a company which is a very well known manufacturer of such valves, so this is just a picture from their website.

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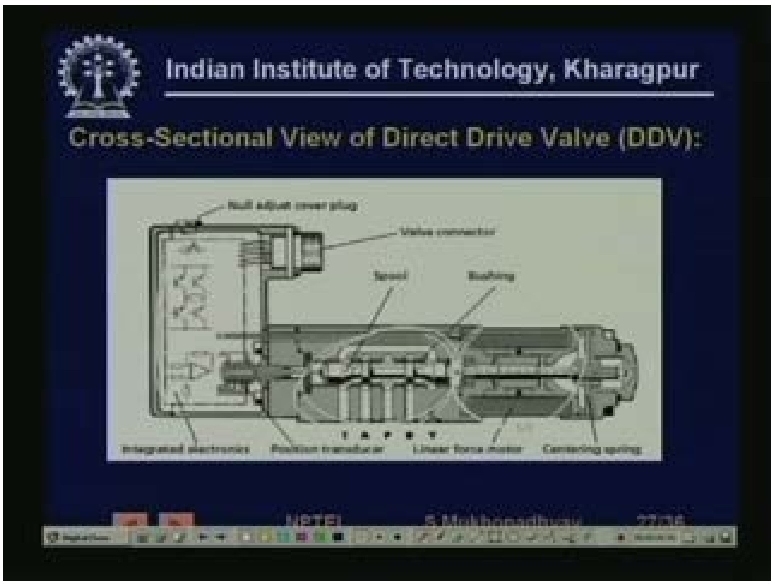

This is a cross sectional view of a, you know direct drive valve, so you have, so you can see that the various parts, this is the electronics, this is the actual valve and this the, what is known as the coil which will pull the spool and here is the position sensor, which is typically an LVDT, you sometimes have a spring here and this is where you make the connection. So, this is just to show you the various parts, the actual geometric how they are packed into a very, that this is a very, very compact devices.

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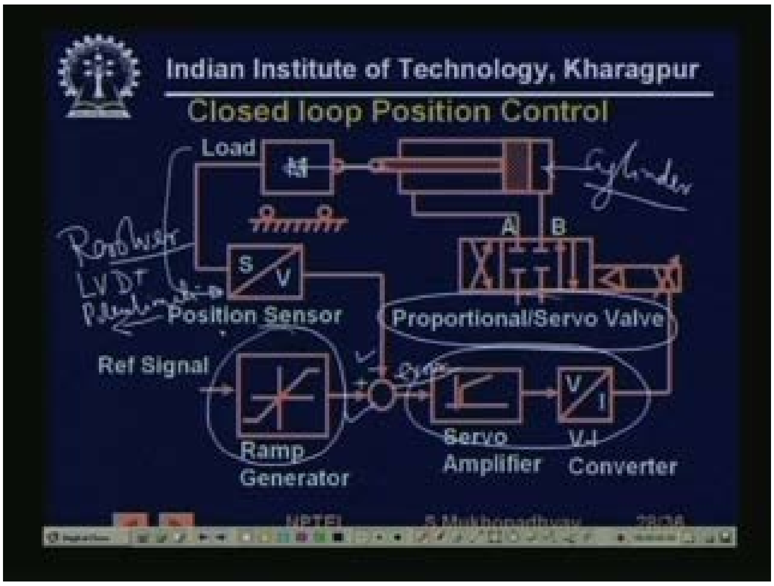

How do you do closed loop position control, so very simple, this is a, see this is a position loop, so you have a proportional or servo valve here, that is driven by this electronics and moves the load, this is the cylinder, which the position of the load is sensed by the position sensor, this is a position typically an LVDT, sometimes a potentiometer, could be a resolver if it is a rotary and these two are compared this and the error is fed.

So, standard position loop, this ramp generator is sometimes used because the fact that the amplitude, you do not need to saturate the amplifier and you want to heavy load should not be, you cannot should not give charge to them, that creates might create the damage to the equipment, might give damage to the load. So, therefore, whenever a position signal has to be change, sometime you need to control the rate at which it should go, you never give step signals generally to this kind of system.

So, you have a ramp generator, if you want to go from one system to another, you go slowly through a ramp, which depends on the velocity level that you want to have, on this load.

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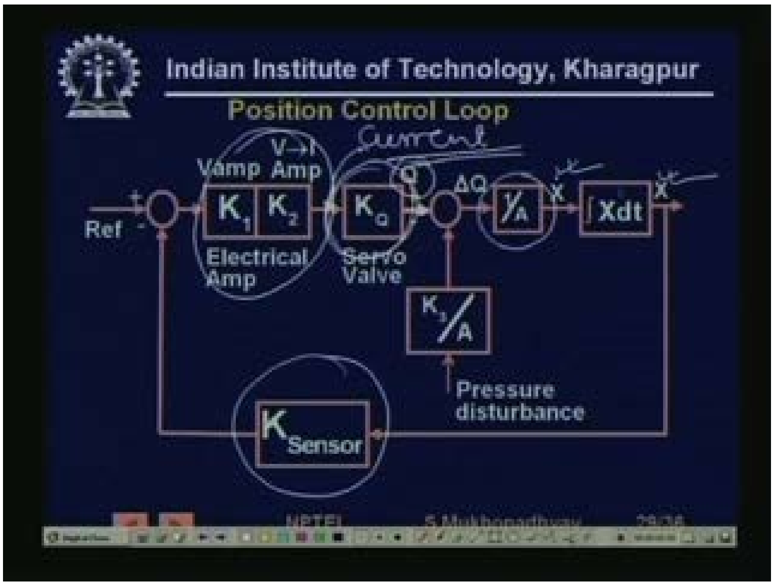

This is a block diagram arrangement of the valve of that loop, so you see that, these are the electrical gains, these are the electrical circuit gains, this is the sensor gain, this is the valve gain, so this is current, this is the current to flow characteristic KQ of the valve. So, when you have a certain flow, then that flow will going in, so flow by area will give you velocity and velocity by integrated will give you position, this is like a block diagram. Similarly, the flow that you are having this, whichever finds assuming that is going through because of your nominal value of KQ that you know.

Sometimes that this flow can be slightly change, if the supply pressure of the pump changes, so to model that they have put a pressure disturbance block. If you want to, because these are you know, I am sorry, because these are very precision control devices generally, so this it is important to understand the dynamics, because there is so much load acting on it. That so much force acting on it, that this dynamics can actually affect, for example, in an aircraft the dynamics of the actuator is very important.

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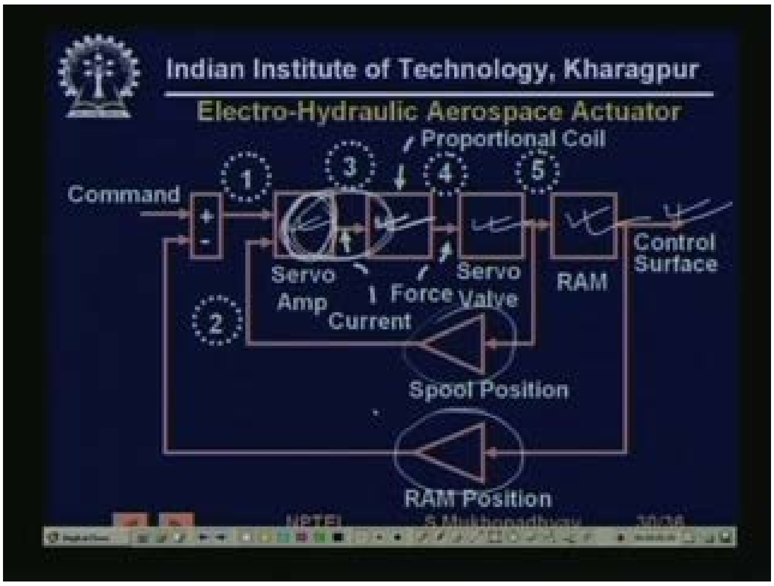

So, in an electro-hydraulic aerospace actuator, you have a similar block, so you see, you can see that you have this is the final, say control surface, this is an typical actuator used is aerospace, very precision actuators. This is the cylinder which is sometimes called a ramp, this is the, so the cylinder is driven by a servo valve, this servo valve is driven by a force motor and the force motor, this is the coil which drives the spool of the valve and that is driven by a, by the electronics and the servo amplifier.

So, there are various feedbacks, there is a current feedback which is inside this, force motor current is sensed and fed back below here. Then, there is a spool position feed back of the hydraulic servo valve spool. And finally, there is a ramp position feedback of the actual control surface. So, these are connected in cascade loops, you can see the, we will not do it in much detail, but the typical drive electronics.

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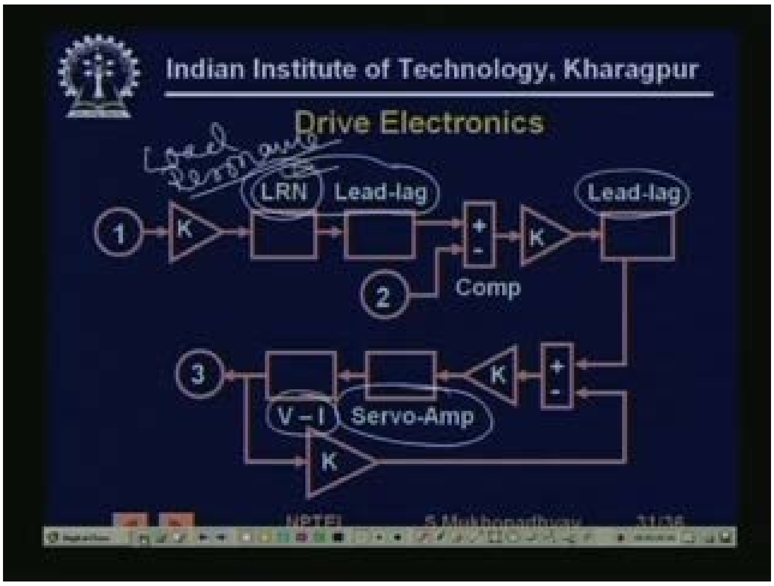

So, you use, all that I wanted to show is that, you have to, there are certain elements for example, you have to use servo amplifiers and V to I converters and then you need various kinds of filters, because specifically because, you do not, you want to avoid giving inputs to your system which may cause things like resonance. So, for that, from that point of view you have to cut out certain frequencies in your input and that is why you need various kinds of notch filters.

So, this is, this name is a load resonance notch, so if you are carrying molten steel using a hydraulic system, then there is sudden natural frequency, if you input at that frequency, then the molten steel will spill over. You have to cut out that frequencies, that as you are transferring, there will be no waves created in the liquid steel or whatever. For these purposes sudden frequencies, ((Refer Time: 53:23)) you know the inputs must be cut out, so this is a typical.

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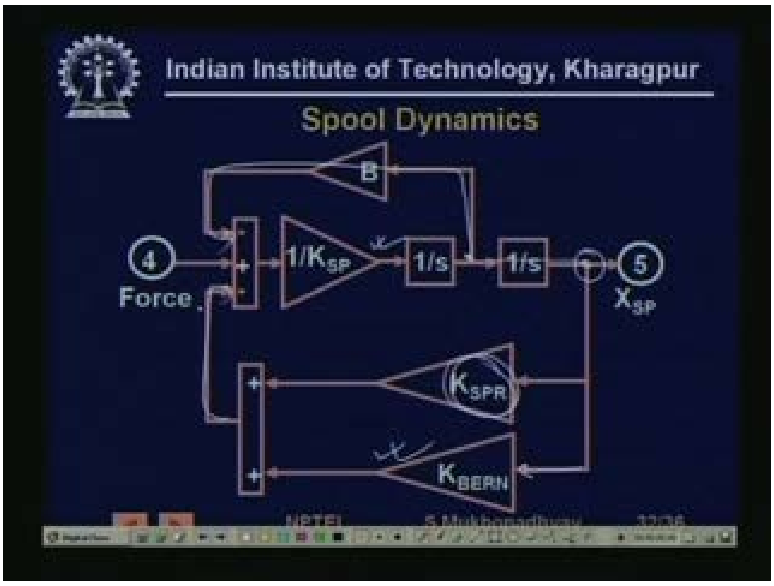

If you see the spools dynamics it is very simple, there is some force acting on the spool which is created by the coil, this created it is creates a certain amount of acceleration. So, this is acceleration, this is velocity, so you have friction feedback and then there is finally spool position and you have two kinds of feedback, one is that you can have a spring, sometimes you know we have seen that, we have centering springs connected, so you have spring force. And you have a Bernoulli force, which is occurring, which is a force on the spool because of that, fluid flowing through the valve. So, there is some force acting of the spool, so these act as feedback elements, so this creates the motion of the spool.

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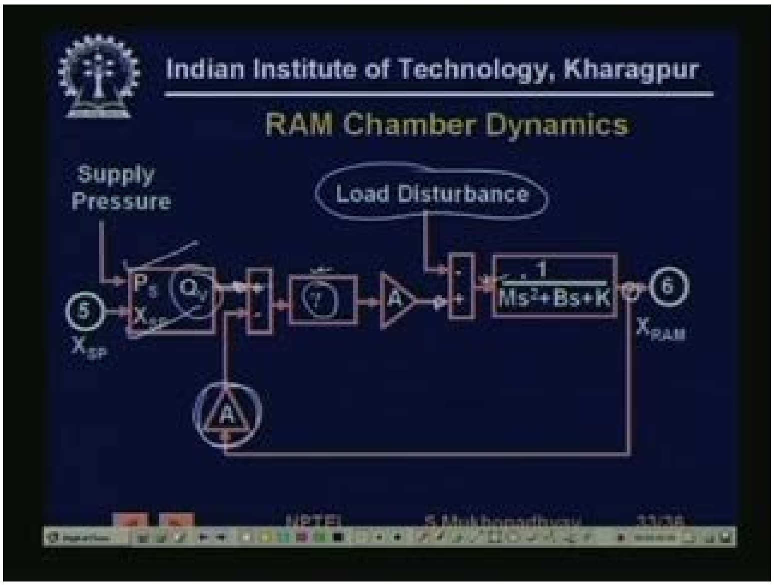

Similarly, in the RAM, the motion of the spool, the flow into the ramp depends on this, depends on the supply pressure and the spool. So, you see that, this is the inlet fluid into the RAM and what is the outlet fluid, if the motion of the RAM is X RAM and this is the area of the cylinder, then this is the fluid which is going out. So, there is a little difference finally and that difference actually causes a, what creates the force, force is created by the compression of the fluid.

So, initially there is a little fluid compression and because the bulk modulus is so high, so that immediately creates a lot of pressure and that multiplied by area, so you get the force. That is the acting force on the cylinder, there is a load on the cylinder also, so the difference actually accelerates the cylinder and creates the motion. So, this is the kind of dynamics that you have on hydraulic cylinders and they have to be precisely controlled.

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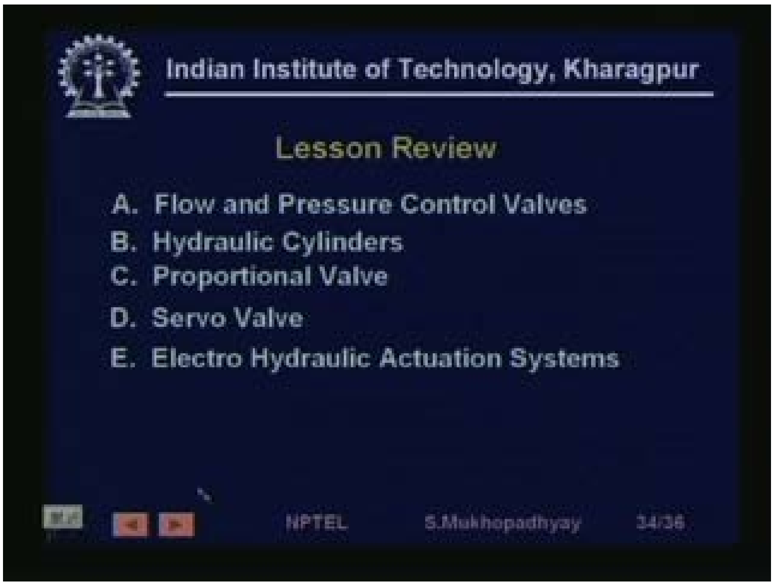

So, we have come to the end of the lesson, we have seen flow and pressure and control valves, we have seen hydraulic cylinders, proportional valves, servo valves, and some hydraulic actuation systems.

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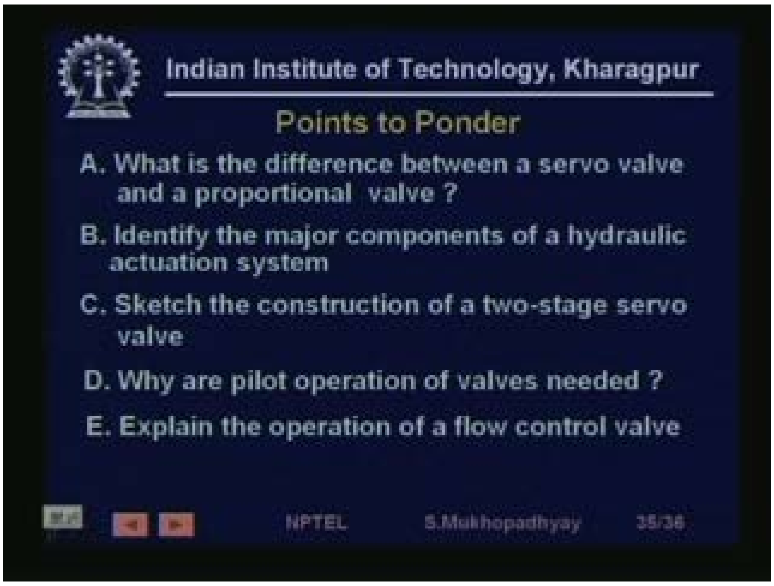

Last, points to ponder, what is the difference between a servo valve and a proportional valve, is it in terms of feedback, is it in terms of performance accuracy or is it in terms of structure, drive, what. Identify the major components of a hydraulic actuation system, this is the one of the major, this question you should be able to answer, because this is the basic, one of the basic purposes, basic instructional objectives. Sketch the construction of a two stage servo valve.

This is going to take some time, but think about it, how it works, especially how the feedback come works. Why are pilot operation of valves needed, can you think of some actual application and explain the operation of a flow control valve, that is interesting, how the flow is controlled, irrespective of pressure variation by a mechanical arrangement, so that brings us to the end of our lesson today, thank you very much.

Industrial Automation & Control

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Lecture – 28

Industrial Hydraulic Circuit

Welcome to lesson 28, of industrial automation and control course under the NPTL program. Today, we are going to look at a very interesting topic, in the last two lectures we have seen various hydraulic system components. In this lecture, we will see how they can be join together to form hydraulic circuits for various kind of the industrial applications, so that is going to be very interesting for me at least to tell you.

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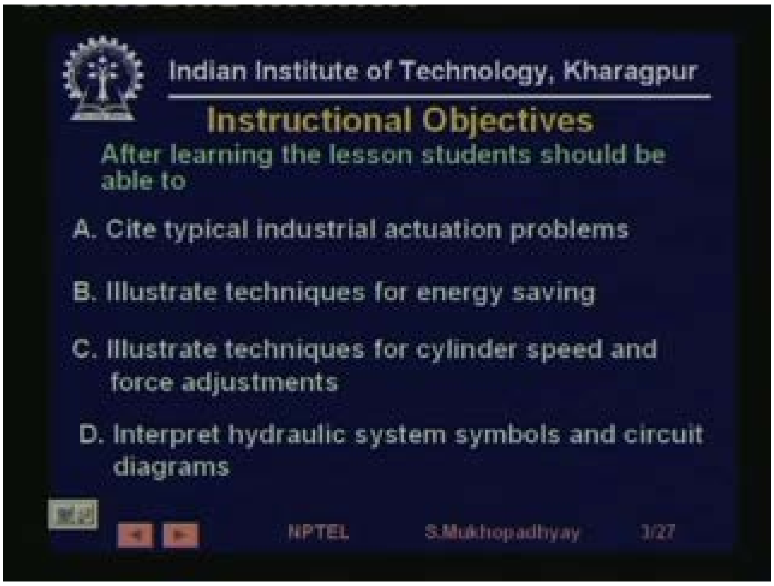

So, looking at the instructional objectives, after this lesson, student should be able to cite typical industrial actuation problems, some very common problems which occur in the case of industrial systems, so then, in many cases we, you know energy is very expensive, so we do we never like to spend energy unnecessarily. So, there are various kinds of energy saving schemes, especially hydraulic systems are very high power systems, so saving energy is important.

So, we will see, how we can save energy for such systems and sometimes we will find that we need to, you know we need to create motion using hydraulic systems. So, we need to adjust speeds, we need to adjust forces, depending on the requirement of the load, so how to do them and finally, we all the circuits will draw using some, using specific hydraulic symbols. So, will see in the course of this lesson how to interpret hydraulic symbols, how to understand, what components are being used and how to figure out how hydraulic circuits work from a circuit diagram.