INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and Control

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Topic Lecture – 34
Hydraulic Control Systems – I

Welcome to today's lecture which is like which is lesson number 26 of the course on industrial automation and control.

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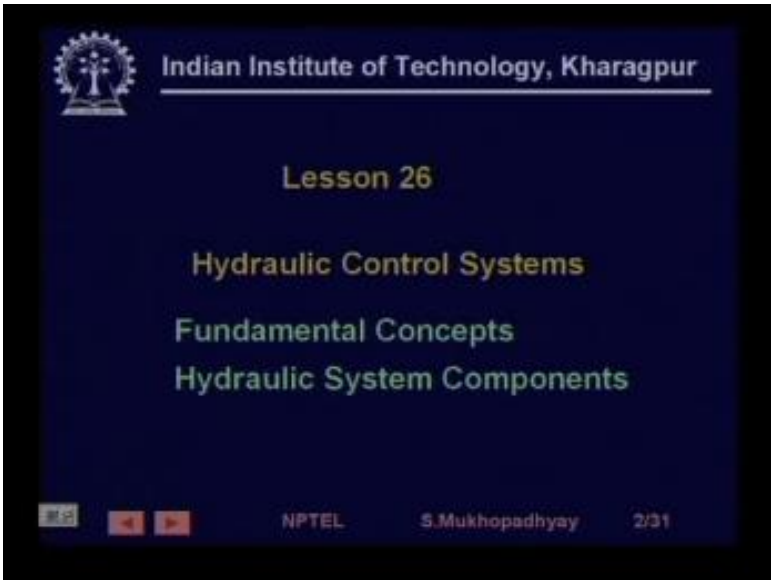

Today we are going to take our first look at hydraulic control systems and we will review some elementary basic concepts and then we will first look at the components which make a hydraulic control systems. In the subsequent lectures we shall see some special components and we shall

see as to how these components can be used to make a hydraulic control system. So we begin here before we begin we look at the instructional objectives.

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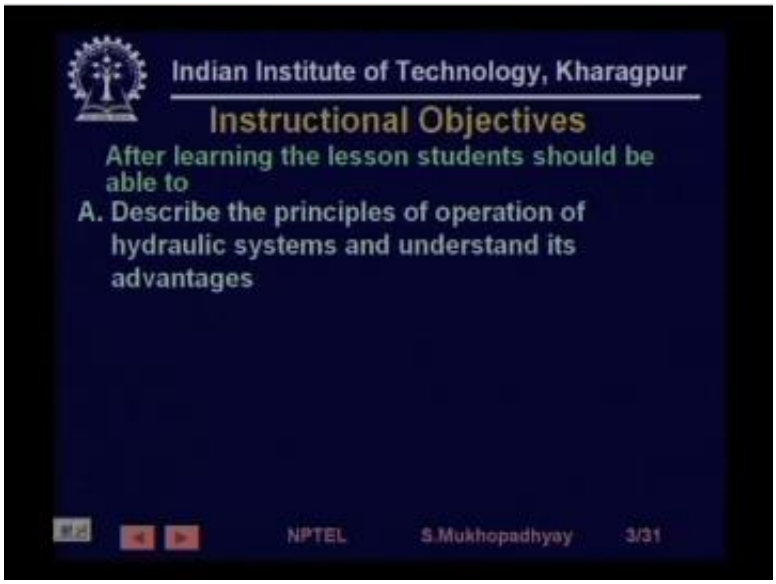

So the instructional objectives are basically to describe the principles of operation of hydraulic systems and understand its advantages what is involved and why it is almost irreplaceable used in certain applications there are certain advantages.

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Then of course we have to be the main purpose of the lesson is to be familiar with the basic hydraulic system components and their roles in the system what they do and describe the constructional and functional aspects of hydraulic pumps and motors how they function, and be familiar with directional valves and control valves they are very important components. So we will take it somewhat detail look at these.

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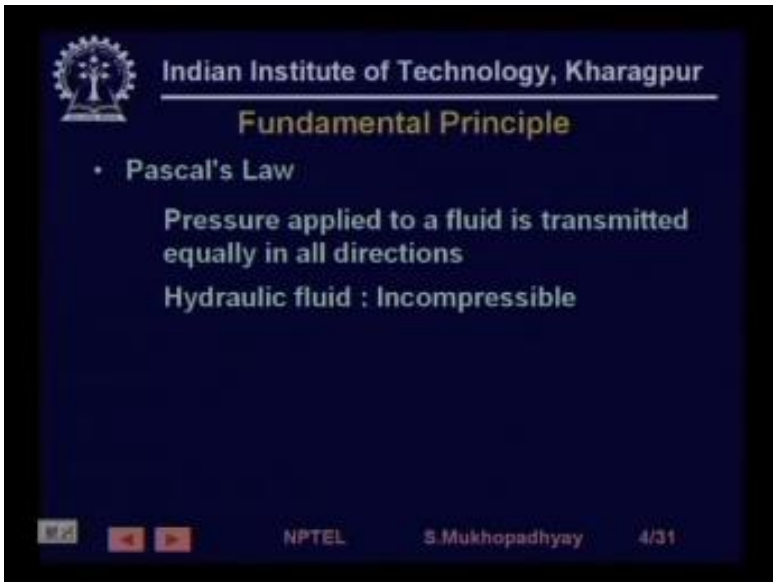

So we begin with the fundamental principle of hydraulics which is based on essentially on Pascal's law which says that pressure applied to a fluid is transmitted equally in all directions. So if we apply pressure in a fluid at a given point then same pressure is transmitted through the fluid which is supposed to be incompressible and gets applied everywhere else. So we actually use this property of incompressible fluids to transmit forces, so we will apply basically hydraulic control systems are used to create motions under in various situations very precise motions against heavy loads.

So high force has to be transmitted and precise displacements and velocities have to be created that is the basic area where hydraulic systems find majority of its applications. So what we essentially are going to do is that we are going to apply pressure to a fluid at one end and the same pressure is going to get transmitted and act on some other body. So when pressure acts on a body it creates force so we expect that force will create a motion right.

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Now as I said that pressure determines force and how does it determine force, pressure is given as force/ unit area of the application of the pressure. So you see interestingly we should look at this, we have also learnt this in school.

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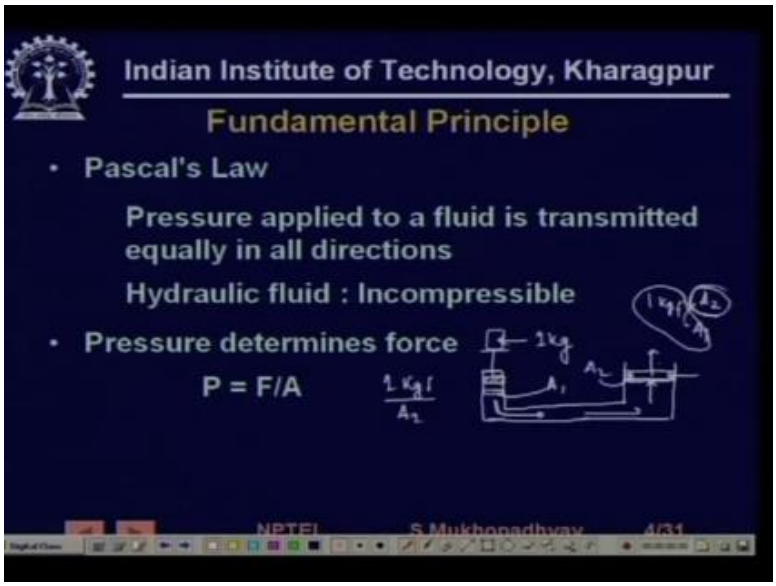

That if we, so you see that if we apply let us let us take this very elementary example which we have, which is the basic principle of a hydraulic press which was one of the first hydraulic machines, which was. So if we have a small piston here and if we have a large piston here, large means the area is large as you can see. And if we place a load so this is let us say 1 kg then the pressure here is basically this one kg force by A1 now the same this is A1 and this is A2 .so by Pascal's law now this same pressure is going to get transmitted and we will act on this area so the pressure on this is also 1kg f /A_1 and the force on this is 1 kg f x A_2/ A_1 because this is the pressure so what is the force it creates on this body into A_2 so you see that we apply 1 kg force here and we have created a force which is multiplied.

So we have created a force which can now if that A_2 / A_1 ratio is 100 then by applying a 1 kg f force at one end we have created 100kg f force at the other at the other end so using this principle it is somewhat like a fluidic lever remember levers that we because of the fulcrum if we apply a small force at one end we can lift a much higher load at another end because of moment balance so here also because of pressure balance the same thing is going to happen.

So we have we can we can multiply we can create every large forces and that sometimes it might create an illusion in one's mind that whether how suddenly without mine does it invalidate any law of physics is energy conserved energy is indeed conserved because energy or power is force into velocity right, so we can look at this.

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So and that velocity comes from flow right so what is the flow the flow is what is the flow rate because let us look at the next diagram then this picture will be clear.

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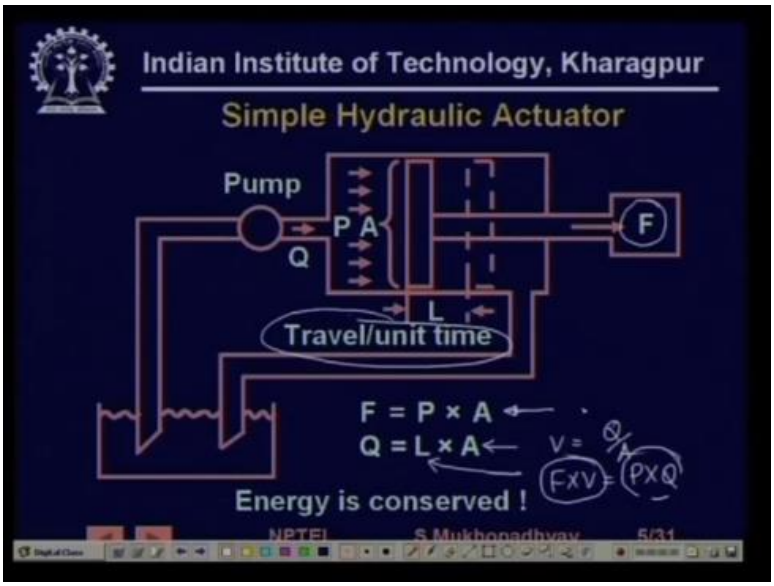

So let us look at a simple hydraulic actuator so you see that we are creating a pressure here so that creates a force F depending on the area and the pressure so F is equal to P x A now let us look at the velocity what is the volumetric flow rate Q that is equal to the area into L where L is the travel per unit time in other words L is the velocity so F is equal to P x A and Q = L x A or in other words we can write that V is equal to Q / A so you see that what is the mechanical power which is developed that will be force into velocity.

So F x V = Pratik: x Q so you see that the area does not come into the picture so the power in the power equation the area does not come into the picture and even if you multiply the force the energy does not get multiplied how can you get multiplied so energy is the same for a pump as we know a pump delivers a fluid at a certain rate volumetric flow rate and at a certain pressure and the pump output power is simply P x Q.

So whatever the area the mechanical power is also P x Q F x V = P x Q so therefore energy is conserved and there is no contradiction so this but never the less so actually what is going to happen is that we will depending on what flow rate we can provide the load perhaps a very high force we can create a very high force but at the same time the rate at which that load which

requires a very high force to move is going to be slow so the energy is going to be concerned that is the basic fact.

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Then so the having understood this let us first look at the let us first for the better part of this course we will we are going to of this lesson we are going to look at the component so let us start looking at the component so the most first component that comes to mind is the fluid, so the fluid itself transmits the plop the power or the pressure, so you create you input the power and that power will in a way that that power travels through the fluid which is incompressible and delivers the power in a different form so the fluid power in terms of pressure and flow gets converted to mechanical power. Now these the certain things to remember that these are these systems are of very precise create very precise motion and therefore requires parts of very precise sizes which move within one another, so there is an amount of friction involved because otherwise the fluid is going to leak out, right.

Unless the parts are time tightly fitting then the fluid is going to leak out all over the place, so therefore there is an amount of friction which is likely and that is going to create lot of problems it going to create heat, it is going to waste energy and it is going to damage the parts. So it is a

prime importance to lubricate the part so that smooth frictionless motion takes place and the fluid itself one of the big advantages of hydraulics is that it does not require any additional lubrication.

Which is often required in electric systems and in pneumatic systems because they do not have an inbuilt lubricant here we have an inbuilt lubricant which is the fluid itself which is used for power transmission even then some amount of heat is generated because of friction and this heat and so there is a need to cool the components because enormous pressure exists and the fluid also cools the components and secondly it also removes the contaminants.

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You know as things move some small particles may be generated by friction similarly small similarly sometimes air may come into the fluid so all these entrapped air, dust particles these things have to be removed from the system and the fluid as it flows it also cleanses this and brings it to the filter where they are filtered. A typical hydraulic fluid actually petroleum oil some cases one uses you know things like water with some with some additives or sometimes water oil mixtures.

But the most popular hydraulic fluid is petroleum oil which is which is very incompressible it has a self-lubricating property the only problem it has it has the easy is that it tends to be somewhat hazardous for fire right, so that is a drawback.

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So it is incompressible lubricating and but combustible, combustible means the flashpoint must be considered. Now what does the so this is a picture which says.

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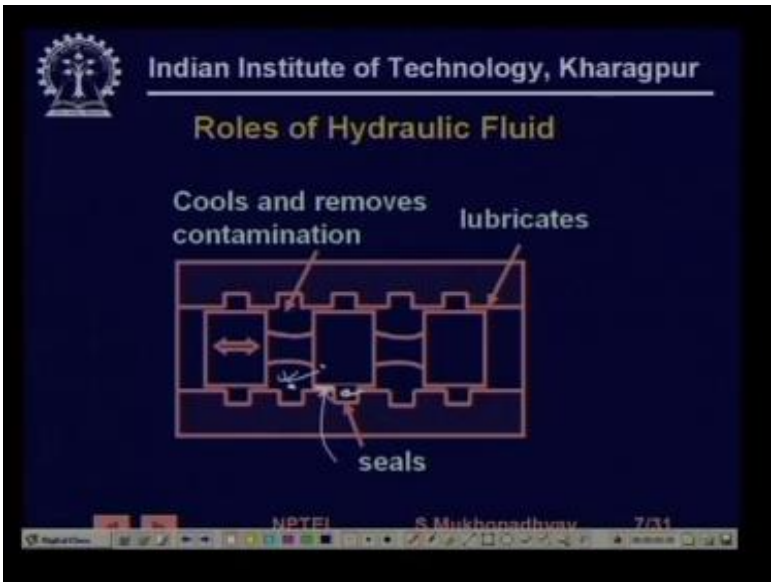

What the what the hydraulic fluid does, so you see that the hydraulic fluid apart from the fact that it lubricates it cools and removes contamination there is there is there is one point that I did not mention that is it seals also so because of the viscosity of the oil if you have if you if you for example the fluid here and the fluid here are going to be effectively sealed by this liquid film. So this liquid film here is going to act as a seal so that this pressure and this pressure do not there is and there is an effective barrier created.

Because if this pressures leaked out then the pressure cannot do effective work so it will be lost so therefore you need to have sealed and in many cases the liquid film itself creates the seal in still other places you have to add additional seals. So that is another thing that the liquid does.

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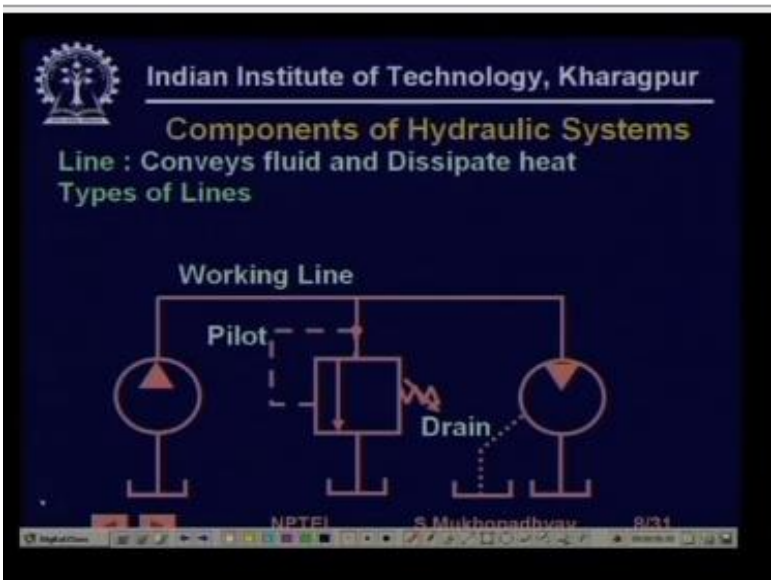

Now how does the liquid flow, the liquid actually flows in pipes now this is you know one of that this is a kind of drawback for the hydraulic system in the sense that you have to have an you have to have some piping and you not only have to have piping from the pump to the load as the liquid is flowing because it is a liquid so you need to also have the return line so that adds some cost and some maintenance.

For example in by contrast in pneumatic systems you do not need those you do not need those you do not need the return line because it can release the air into the after which has done the work and it has come to atmospheric pressure you can just release the air into the atmosphere but they are by saving the cost of return line but that is not the case for hydraulics you have to have a return line. So there are various kinds of lines which are used in a hydraulic system.

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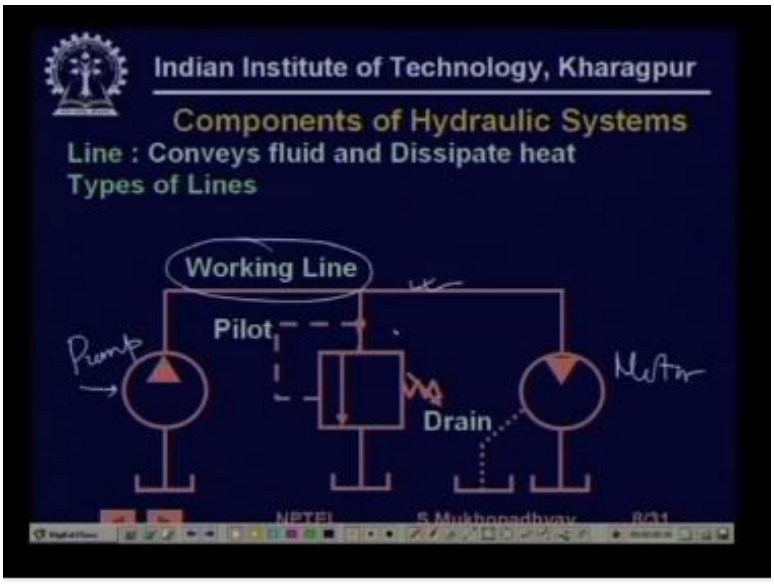

For example the this is this is supposed to be a pump and this is supposed to be a motor, so the pump is creating pressure which is moving the motor creating the motion, so you see that there are some lines which are shown as farm lines through which the actual liquid flows and transmit the power they are called working lines then sometimes there are you have to create some additional pressures at various points so they therefore that for control that is not for transmitting the power but for controlling the direction sometimes releasing pressure so you need to create pressure at different points you sometimes you have to use separate lines and these lines are called pilot lines.

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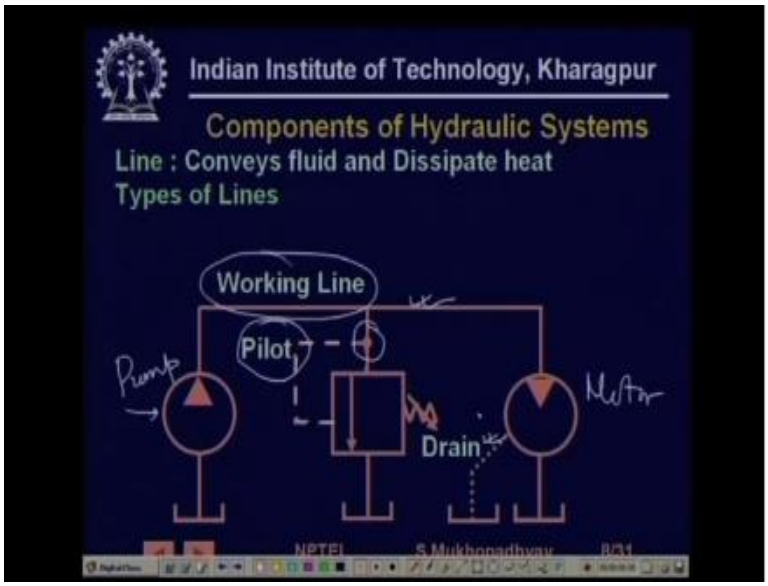

In this case in this particular diagram the pilot line has been derived from the working line that may or may not be the case all the time and the pilot line is shown like you know in Long dashes similarly you have to have some drain lines because some liquid is going to get is going to leak out so you need to collect them so that they you know they are they do not spill here and there they are not lost etc. So you need to add some drain lines.

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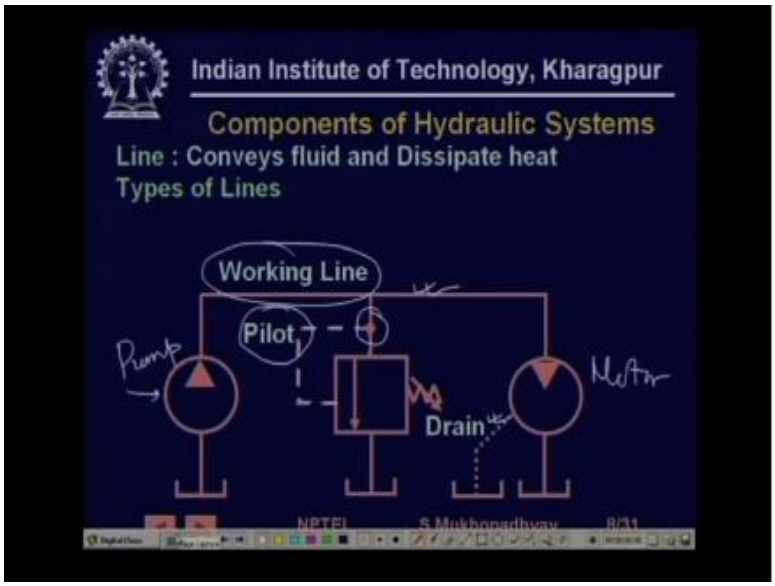

So you also have drain lines which are shown in short dashes so these are the typically deserve the three kinds of lines through which fluid flows in a.

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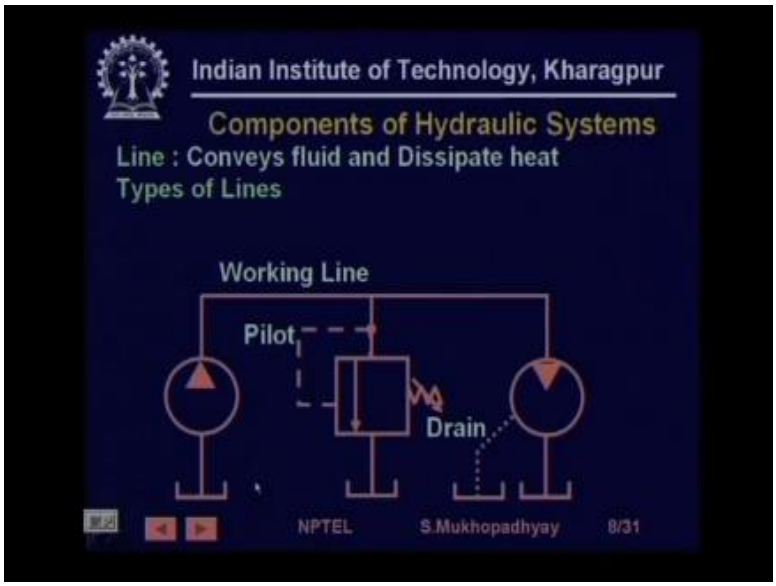

Hydraulic system.

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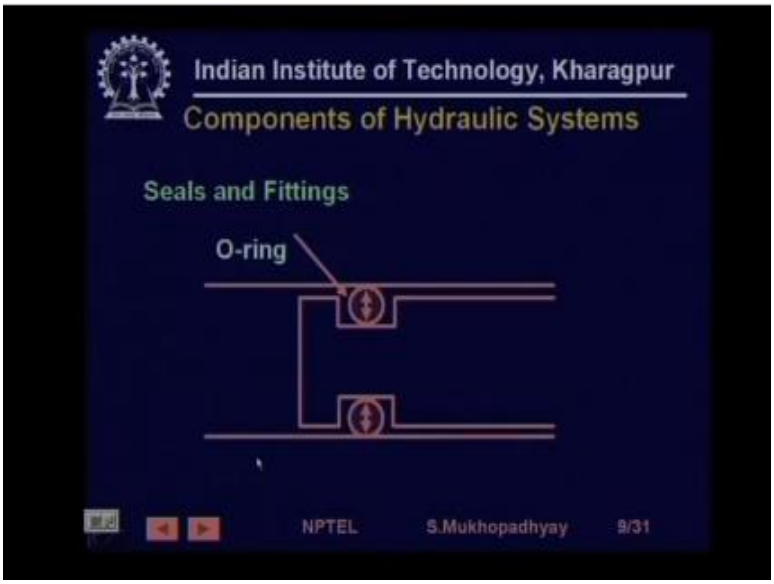

Then you need some as I said that you need seals and fittings sometimes the seal is a natural seal provided by the liquid film but sometimes you need two fittings means be very whether you have you have pipe you have seen in your own house in the bathrooms that whenever you I mean some fluid is flowing you need various kinds of fittings unique various kinds of joints right you need the pipe itself which can be farm pipe typically in the bathrooms it is sometimes a metal you know fixed pipe sometimes.

We have we now have polymer pipes so you here also you can have flexible tubing sometimes you can have hoses which are you know metal reinforced polymer pipes so various kinds of pipes can be used and along with that various kinds of fittings and scenes must be used so this is we are not going to dwell much on that only has to show just to show what kind of a ring.

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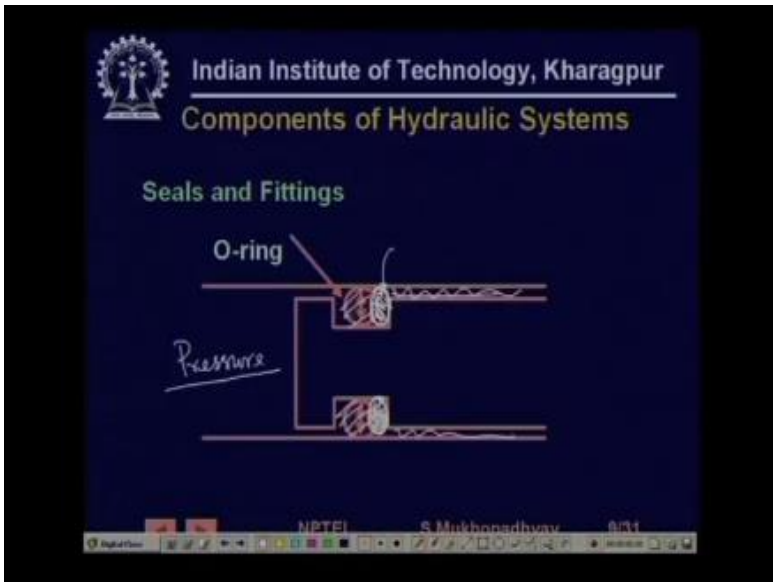

For example if you have this is a noting which is a common very common type of seal so you see that as this is moving as this if this is the this is when it is moving against pressure this is a scene in there so what happens is that this scene is going to be pressurized and it will come and settle here right so what it is actually pressed so when it will come and settle here it will effectively settle it will effectively seal this part from this part so this ring this is a rubber tube so it will come an under pressure it will come in it is a self-sealing.

Under pressure it will provide a C so such seals are various kinds of scenes are used it is very important it may not be we may not be dwelling with it but unless these things have properly done you're your hydraulic system is.

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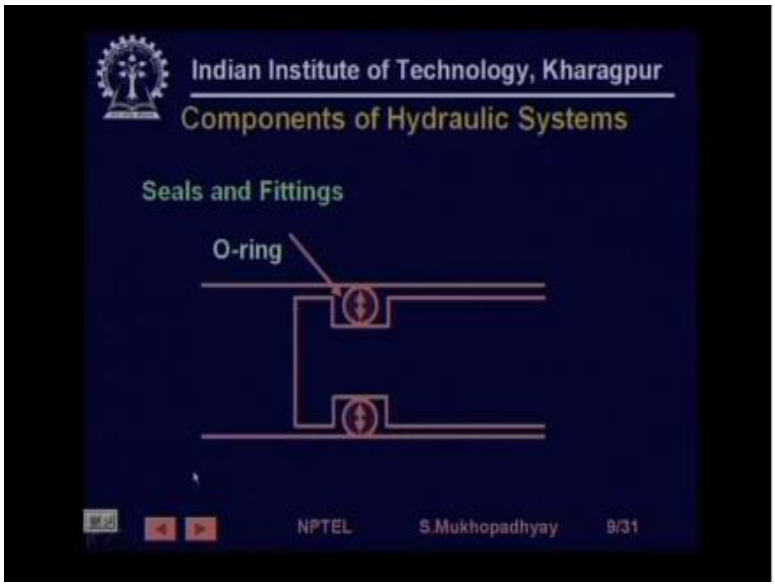

Not going to work and it will be a lot of problem for the maintenance so from the maintenance point of view these things are very important.

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Then we need have a reservoir in oil is continuously circulating so it is starting from a reservoir the pump is sucking the oil and then delivering it at a pressure and then it is flowing through the system and then it is coming back to the reservoir right so but apart from the fact that the reservoir holds the fluid it actually does many other things so we will so it holds the fluid obviously but it does to other things for example it dissipates heat in there deserver the liquid gets cooled and it allows entrained air to escape so this removal of contaminants is done partly in the filter which is also connected closed on the pipeline close to the either on the return line generally on the return line, and so that removes small particles from the fluid and in the.

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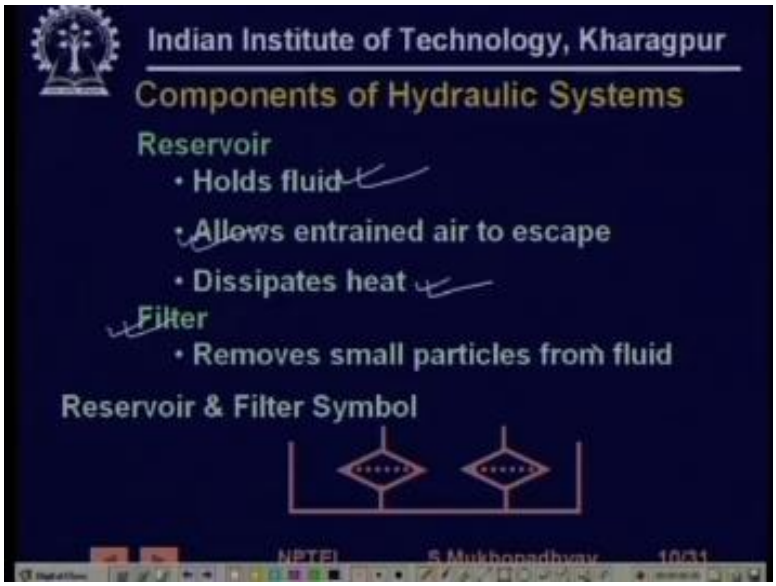

In the reservoir the entrained air part air bubbles get removed and removing entrained air bubbles actually very important because if you have, you can well imagine that if you have a fluid and in which if you have entrained air bubbles then the fluid does not remain incompressible anymore, because if you apply pressure to the fluid it is the air bubbles which will get compressed and so therefore the fluid itself will get compressed.

So in technical terms the bulk modulus of the fluid will can fall drastically if you have trained air in it, so is very important for as we said that for effective transmission and fast quick responding transmission that the fluid is incompressible so therefore it is important that air bubbles have to be removed and they get removed at the tank.

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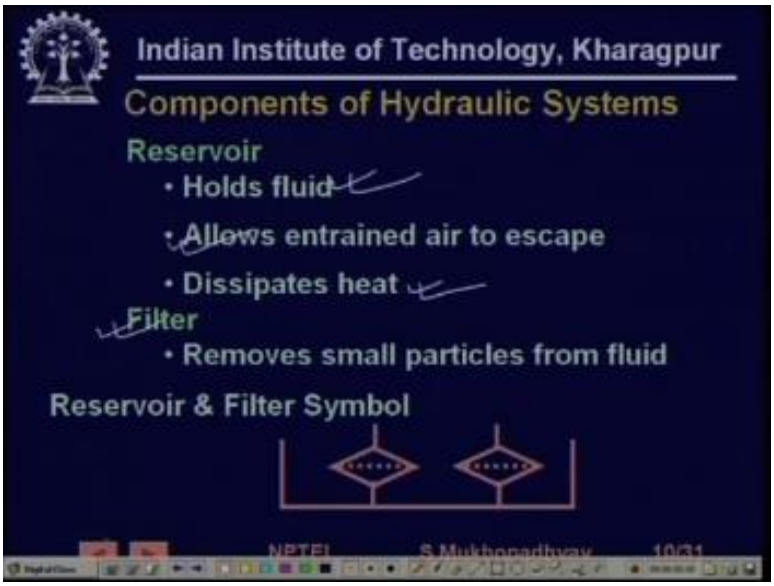

So this is a when we will draw hydraulic circuits we are showing simple side by side because in the coming lessons we will draw hydraulic circuits so that we understand, so this is a reservoir symbol in which we have two filters.

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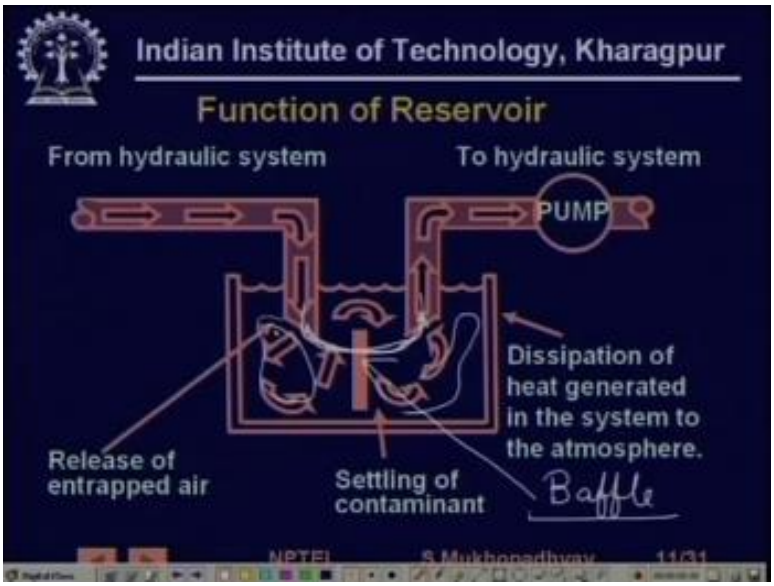

So coming back, so you see that the functions of the reservoir are shown so from hydraulic system there is something called a baffle. So this is created so that directly, otherwise if this is not created the this part of the fluid because of this low resistance directly fluid from this will get sucked into the pump so therefore these fluids will not get sucked and the these fluids will not spend time in the tank. So therefore, they will not get cooled their airs will not get removed, so therefore a baffle is placed so that the.

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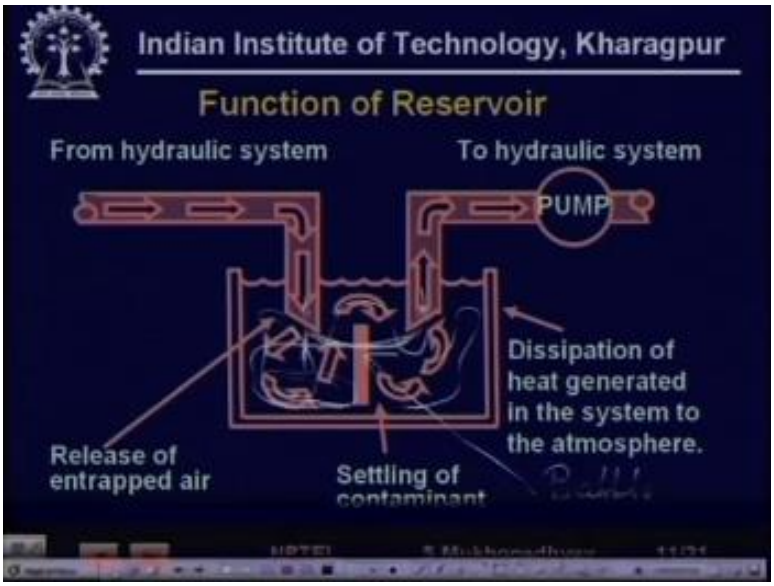

So the fluid which comes settles around this point and the fluid which has come earlier actually go and enter the pump. So this is just to create that, so this just shows that how the pump is how the reservoir does its job.

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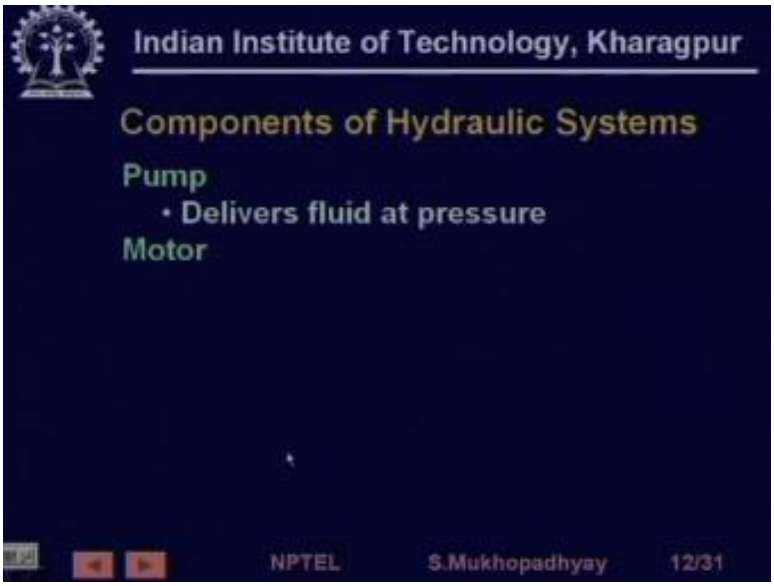

Now we come to the main component, so firstly is the pump as you have seen that the pump is the generator of the hydraulic energy that is a delivers fluid at a flow rate which is determined by the load and add a given pressure. Now who drives the pump, the pump cannot generate energy by itself, so the pump has to be generated again by some other means sometimes it is an electric motor which will drive the hydraulic pump, sometimes especially you know hydraulics is used very much in aerospace applications, sometimes you can couple the engine along with the I mean maybe bleed some gas engine gas and then run a special type of motor which will move the pump. So in other words the pump needs a prime mover and creates and delivers fluid at a given pressure.

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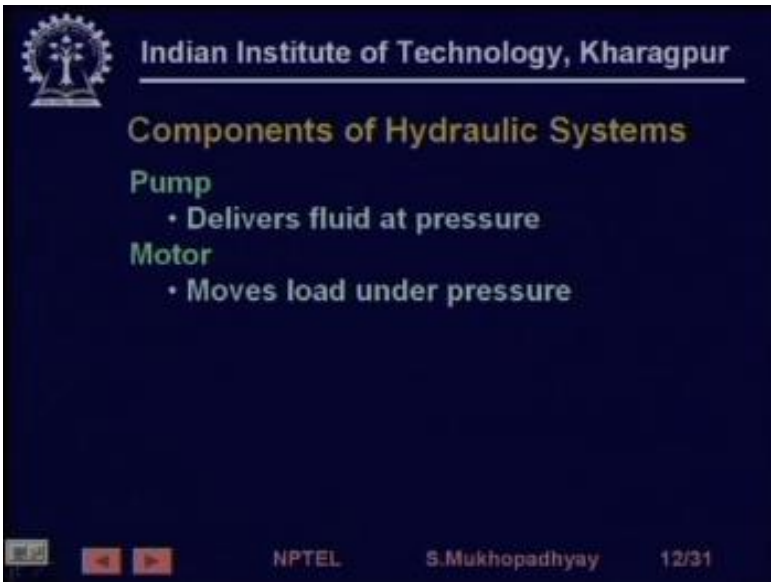

The motor on the other hand is the counterpart of the pump the motor receives the fluid under pressure and creates motion against the load. So we generally so the pump is like a battery while the motor dislike the load.

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And these are the symbols so you see that the pump symbol is like this and the motor symbol is like this and there are some reversible you know, if the pump and a motor are reversible that is they can rotate in Road in both directions then this is the symbol oh sorry.

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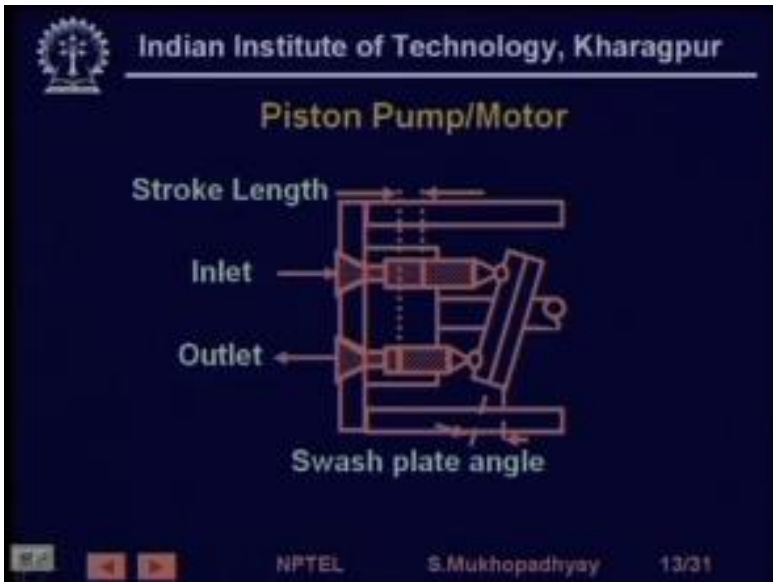

There are various kinds of pumps which are used we are going to look at three typical types of pumps so we will first look at the piston pump or the motor in both cases the construction is quite similar only thing is that in the pump the motion will be created by the prime mover and the fluid will be delivered while on the motor the fluid will be will come into the motor and the motion will be delivered so this is only different that is why we have showing them in a uniform manner so the first thing is the piston the axial piston pump which operates like this.

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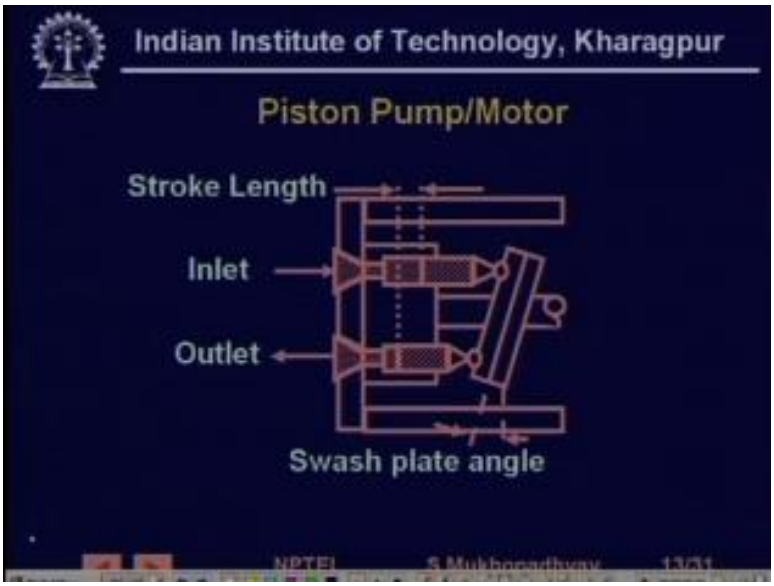

So you see that you can imagine that there are let me try to show you that along the periphery of the motor along the periphery there are a number of such pistons so you can if you if you take a cross-section you can see this diagram right. So there are this is one piston so along the periphery this is one piston the here if there is another piston here there is another piston so along the periphery there are a number of Pistons two of them are being shown right and this distance at the end is actually connected by a plate so you see the plate in the figure so see the plate in the figure.

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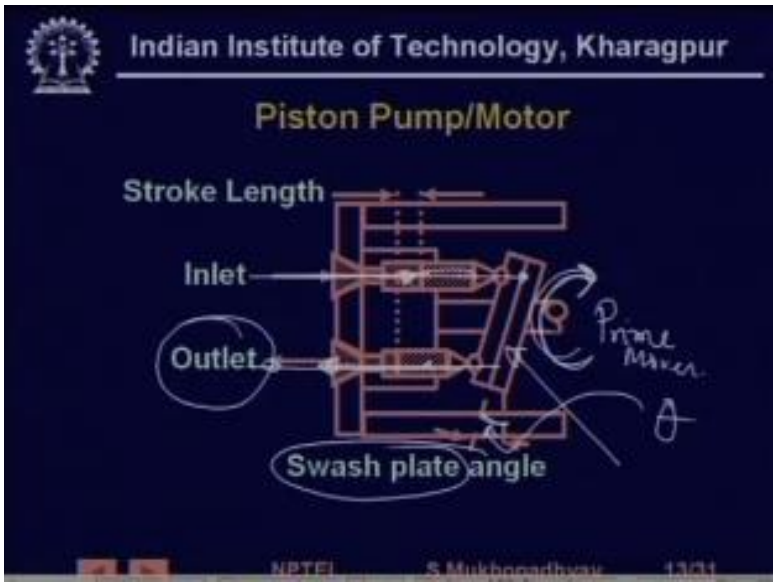

Now you see that the play it is now you should see the plate the plate is connected at an angle σ what does it mean that let us take the case of the pump so the pump is being rotated in this way by prime mover right so one now what you while it is rotating you can imagine that this is why while it is while the disc is rotating here it is pushing and here it is pulling the piston right so what is happening is that here the fluid is being sucked in from the reservoir and here the fluid is getting delivered into the outlet.

So because of this angle the fluid is getting sucked here and then it is getting delivered into this outlet so this is this is called a swash plate and this delivers pressurized fluid at this outlet on the other hand if you apply pressure fluid here and then the fluid will come out through this outlet and this swash plate will actually rotate in this direction so that is the function of the motor.

So this is the way piston pumps move and naturally the flow rate that you can deliver depends on the number of number of cycles of the what is what is the total flow rate that depends on the number of pistons and the number of so at during one rotation each piston will deliver a fluid which is equal to its own volume so therefore if the number of rotations per second is X then X into that number of volume will actually get delivered in that pressure.

So this you can using this you can deliver compute the volume flow rate we are not computing anything we are object is to understand only the operation.

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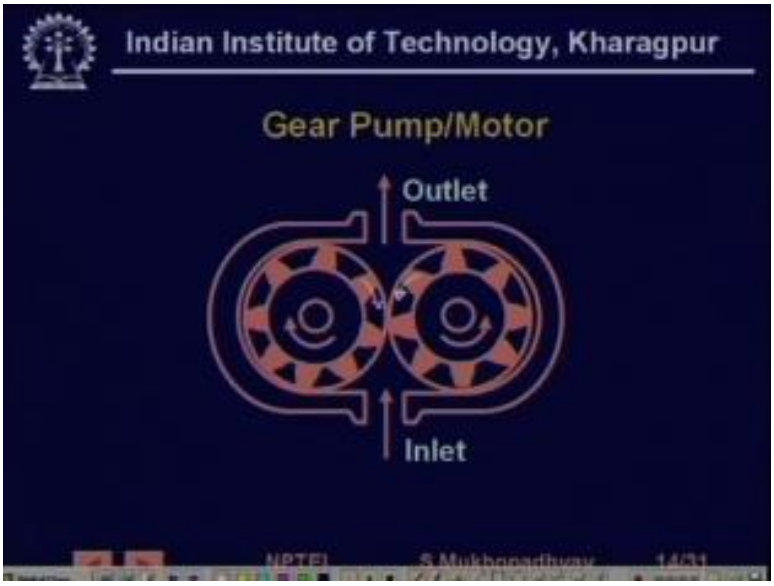

On the other hand look at gear pumps in the gear pumps you have meshed gears so what is happening you can you can imagine that as this gears are rotating so as this gears are rotating in this zone as this see this teeth is moving this way and this teeth is moving this way. So here if they are compressing the fluid and some high pressure region is created, on the other hand here the meshed teeth the actual drawing is not actually there has to be much closer meshing of the teeth so here the this these teeth are actually going away so they are opening up in one place they are closing their like this like this so in one place they are closing so when they are closing they are there they have a tendency of creating a pressure.

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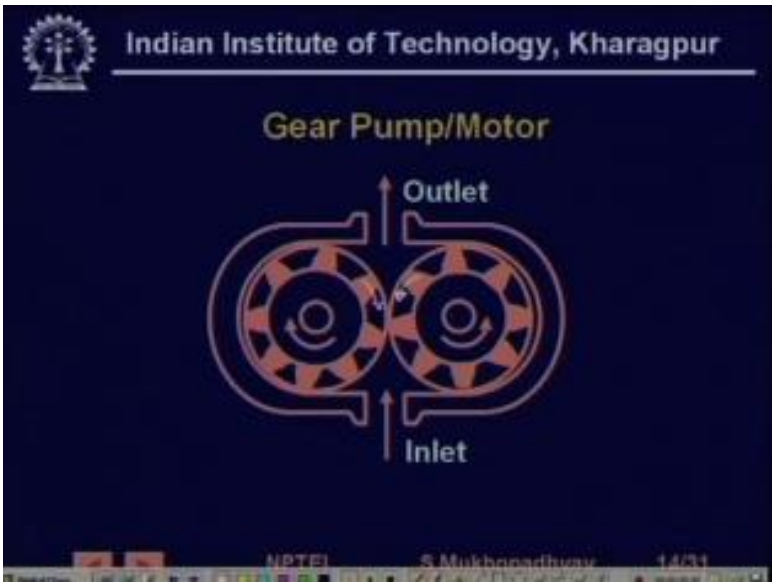

On the other plate they are they are actually opening so when they are opening here you have allow pressure region so obviously this low pressure region will suck in fluid from the inlet and this high pressure region will actually drive the fluid at the outlet, so this is the way the gear pump works so on the other hand if you if you in the case of the motor again if we apply pressure here and if you, what will happen is that then it will rotate in the other direction so it will move in the other direction this is get forced and then it will it will open in the other direction and you go out.

So this is you see these two these axial piston pumps in hydraulics we need to have the rotational speed and the fluidic rates are I mean very proportional in the sense that every time if an axial piston pump or a gear pump rotates at a at a certain rate then irrespective of the pressure a certain volume of fluid will get delivered per second right so the flow rate is directly proportional to the rotational rate of the shaft.

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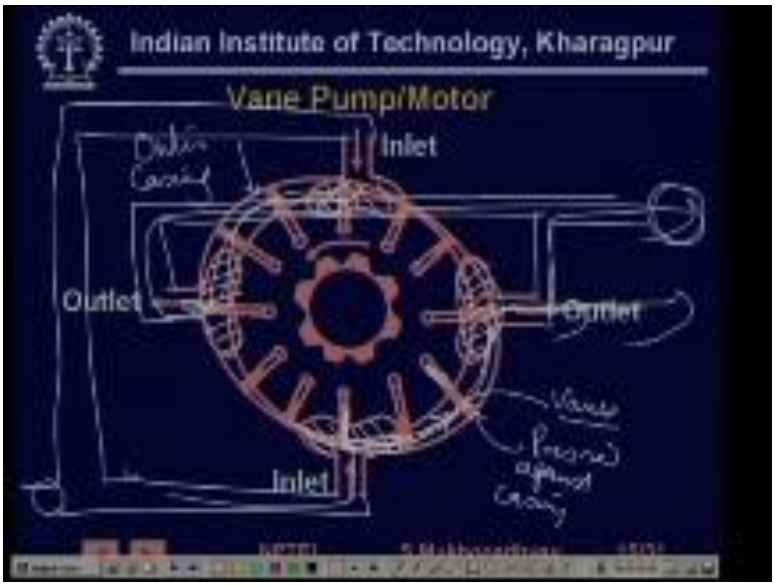

In this is the third kind of pump which is called a vane pump here what is happening is that you see that this is the outer casing this is the port through which fluid is going out and this is the port through which fluid is being sucked in these are the ports so you can understand and these are these are the veins these are the veins which are spring-loaded actually this is not shown so this actually is pressed against the casing here there is a spring pressed against casing, so what is happening you can again see here that here as it is moving the vein is always pressed against the casing.

So it is actually trying to take the fluid along the casing so this much of fluid is being pushed so it sort of scrapes the fluid and takes it here and as it comes here it is getting that is getting compress it gets delivered similarly so that is why here the fluid goes out and here it gets collected similarly here it gets collected and here it goes out so you see that in fact now you can now you can collect you can actually connect these outlets together and make a make one outlet and similarly you can have one Inlets.

You can have one Inlet so then the fluid will get go this way and from here it will go this way and I mean rather finally it will go so here you will get the overall outlet and here is the overall anklet so this is the way of pump works very simply speaking.