Control Engineering
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Lecture - 16
Models of industrial Control Devices and Systems (Contd..)

Well friends, having discussed electrical devices, electromechanical devices and industrial control systems using this to these devices we cannot turn our attention to another important aspect of industrial control devices and systems and that aspect is using hydraulic devices.

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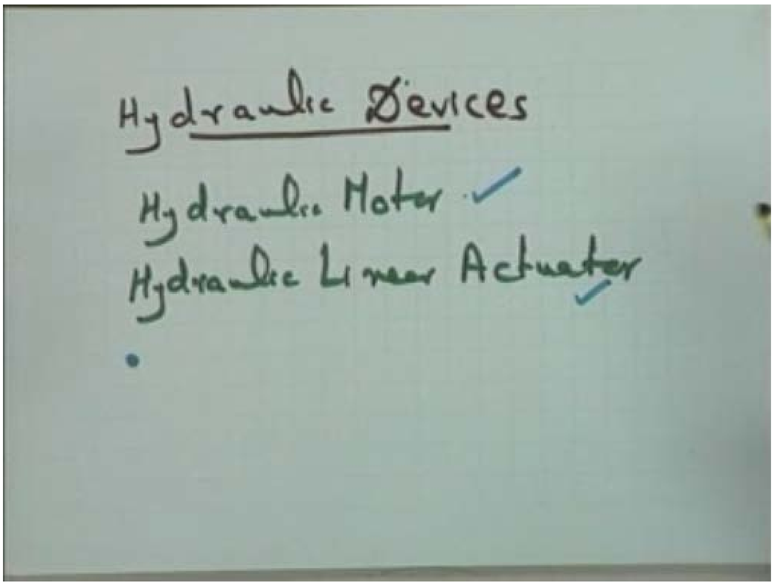

So I take up today with you hydraulic devices and the use of these devices in industrial control situations. Basically I will consider a hydraulic motor. A hydraulic motor will be capable of giving us the linear as well as the rotary motion though the linear motion hydraulic motor is normally referred to as, commonly referred to as hydraulic linear actuator which is going to give us a linear motion in response to the apply torque.

Now, before I take up the working of the hydraulic motor let me just see that what are the basic ingredients, what are the basic features of hydraulic motor vis-a-vis electric motors. Electric motors we have already been using and we know the characteristics of those electric motors. In the case of hydraulic motors what happens, for the same horsepower for the given horsepower the size of the hydraulic motor is smaller. So it means naturally for very large power applications your choice is going to be hydraulic motor and not an electric motor.

Secondly, you see, hydraulic motor is more rugged and the effect of vibrations etcetera is less in the case of hydraulic motor and it is fast that is it can accelerate the load; it can decelerate the load faster than the corresponding electric motor. So it means there are certain features of hydraulic motors particularly the size and better transient characteristics which make hydraulic motors very useful a good selection for all those applications which demand high power.

Well, there is certain cost also to be paid and the cost of the hydraulic motor is higher compared to the corresponding electric motor and you can say that the hydraulic motor the fire hazard the fire risk is there more in hydraulic motors. The oil problems, you see, in the case of electric motors you have got a source the electric source very easily available to you but for hydraulic motors you will have to create the hydraulic lines in the hydraulic source of power. So all these things are there and you have to properly wave you have to properly give a balance between the hydraulic motor and the electric motor when you would select it for a particular application. So out of these two, that is, those for the rotary motion and linear actuator for the linear motion I will like to first take up the linear actuator; a very simple device, let me say that this is the basic linear actuator.

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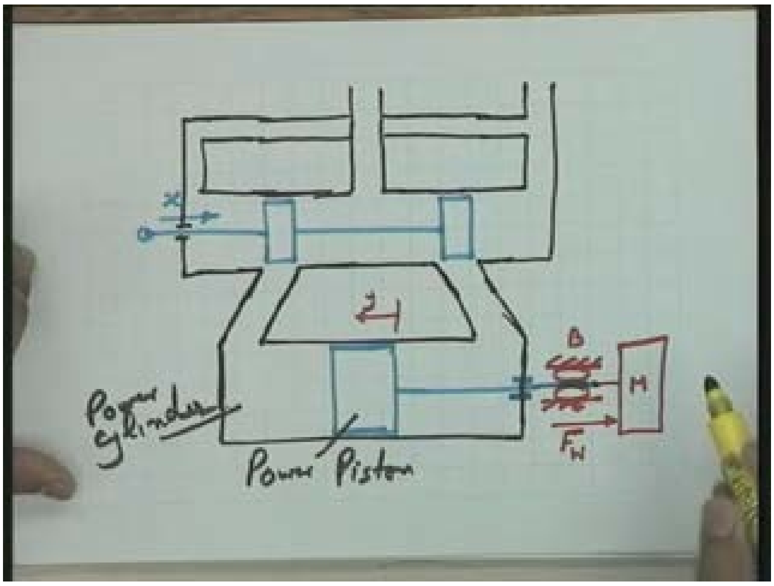

Let us see how does it work and what are these various components of this actuator. I say that this is you are power cylinder, why the name power cylinder given to it because this cylinder creates the motion of this particular piston power piston which is going to move the load. Here is the load which requires a linear motion and the linear motion of the load is given by y. the basic parameters of the load I have taken over here as M the mass B the viscous friction and F W I take as a disturbance on this particular load. The parameters are equivalent to what we have been discussing in the earlier systems.

Now just see, this movement of this power piston is going to move this load in this linear way in this translational way. Now let us see what is the input to this particular system. This particular valve I say that it is a spool valve, these are the spool valve land let me call it and the total assembly is a spool valve. This total assembly is a spool valve, here is the spool and these are the two lands of this particular spool. x is the motion of this particular spool it can be in both the directions of course and this x is the input to the system a hydraulic motor the input output variables are the following: x is the input and y is the output, the only thing is that the x input requires low power because this is a spool a lighter spool, well, the y movement is created at high power because it is able to move this particular load.

So you can say effectively, if you take input as x which is displacement and you take output as y which is again displacement effectively this particular linear actuator is nothing but a power amplifier. Low power at this particular point gives rise to high power at this point which is able to move your load. So I will say that these two lands cover or uncover these two ports; this is control port 1, control port I call it, 1 and this is control port 2 these are the two control ports, this is the spool valve movement covers or uncovers these two control ports and the movement of the spool, should be very clear now, controls the flow of hydraulic fluid in this particular power cylinder.

From where is the hydraulic fluid coming?
Let me say that this is the inlet port. The hydraulic fluid enters this particular port I call it a supply pressure P s, this is the inlet port. I now need your attention. Once the basic system working is clear the mathematical modeling will become straightforward I tell you. This is the inlet port the hydraulic fluid coming at a pressure P s and this is the outlet port or the drain (Refer Slide Time: 7:50) so it means in this particular case the worked up fluid is going out into the sump or the reservoir through this particular drain and let me say that the pressure of the outgoing fluid is P r the reservoir pressure.

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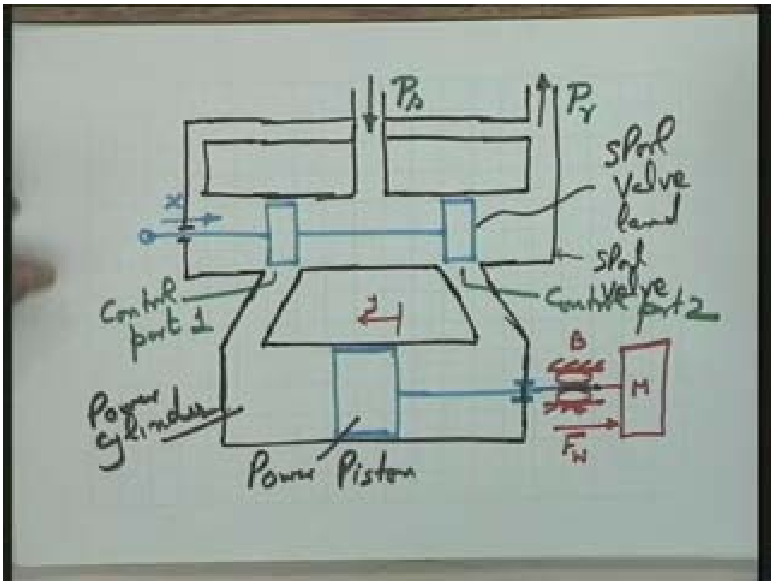

Now this point at this juncture may be noted that as soon as the fluid leaves this particular spool valve this reservoir pressure or P r pressure will be slightly more than the atmospheric pressure, I think it is intuitively clear. But to make our model simpler I will assume that this P r the pressure of the oil going to the reservoir will be taken as equal to atmospheric pressure which has been taken as zero gauge pressure. See the approximation involved. It will be slightly above of the atmospheric pressure but I am setting it equal to atmospheric pressure to make my model simple. So P r is the fluid going to the reservoir and this is the pressure and P s is this supply pressure. You will please note, though there are two ports 1 and 2, two drain ports are there but I have connected the two ports through a suitable pipeline (Refer Slide Time: 9:04) so I can say that I have one control port, second control port, this is the supply port and this is the drain port and therefore this spool valve under consideration is a four port device because the two drain ports have been linked by a suitable pipe and hence the total number of ports in the spool valve is four. One, the supply and this is the reservoir and two control ports. I hope as far as the device is concerned this should be more or less clear and we can now see the working of this particular device.

The objective you see you have to keep in mind is this that for a small displacement x you get an appropriate displacement y which moves the load and the dynamics of the system naturally will come into picture, y and x will not be related by a static relationship; the dynamics whether it is a first-order dynamics, second-order dynamics or higher order dynamics that also we have to see. So this is the total picture of the device called a hydraulic linear actuator (Refer Slide Time: 10:13) extremely useful device as far as industrial control applications are concerned.

Automobile power breaking is for example is a hydraulic linear actuator; cranes do have hydraulic linear actuators. you see, think of any application which requires large power you will find hydraulic linear actuator is the power actuating device it is such a versatile device in using industry. Now let us go to the modeling of this particular unless there is a question on its working and if there is a small point also I hope during the derivation of its modeling that point may become clear otherwise I will like to welcome questions from you.

In this particular case I first assume the neutral position. What is the neutral position? The neutral position of the spool valve is the position which completely shuts of the control ports. See this point please. Step by step we will move so that in a sequential manner we are able to derive the transfer function of this device. the neutral position is x is equal to 0 position and corresponding to this position though I have shown certain openings you see as far as the control port and the spool valve is concerned you will find that there are certain openings available. But you assume, ideally speaking, the spool valve or this land is able to completely close the control port in the neutral position, in that particular case what will happen please; since at x is equal to 0 the two control ports are completely closed there is no movement of hydraulic fluid possible and unless the hydraulic fluid moves in the power cylinder (Refer Slide Time: 12:02) the power piston cannot move and therefore the load is also in its so-called equilibrium position and let me name that y equal to 0. So it means when x is equal to 0 decidedly y is equal to 0 is the corresponding desired position. Of course disturbance is can move y but let me assume that I am in the equilibrium position the disturbances have not yet acted upon the load so corresponding to that equilibrium position x is equal to 0 and y is equal to 0, I hope this is alright.

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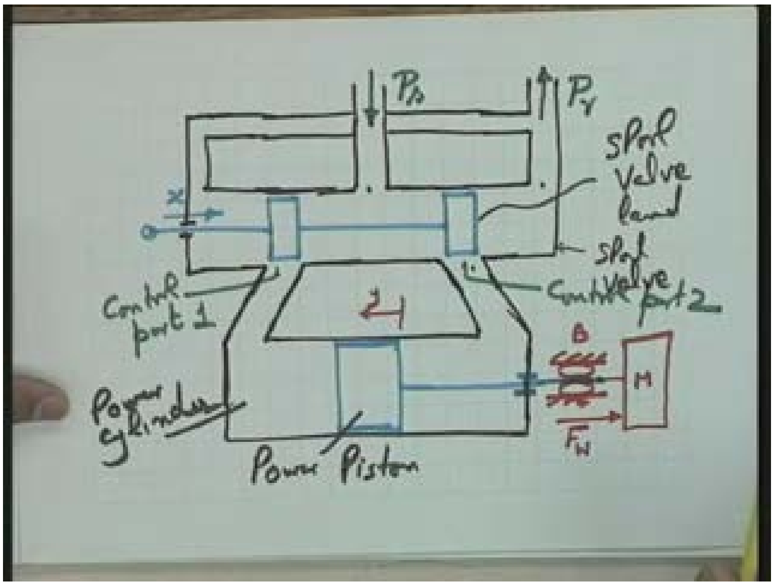

Now look at the control ports once again. I said that this completely covers the particular port. Unfortunately it is not possible; there will always be some manufacturing tolerance. It is absolutely not possible that this will completely cover it so you can either, you see the construction, two-way construction is possible, either it may over cover it or it may cover it slightly less. That is, I will take this slide and bring it back again.

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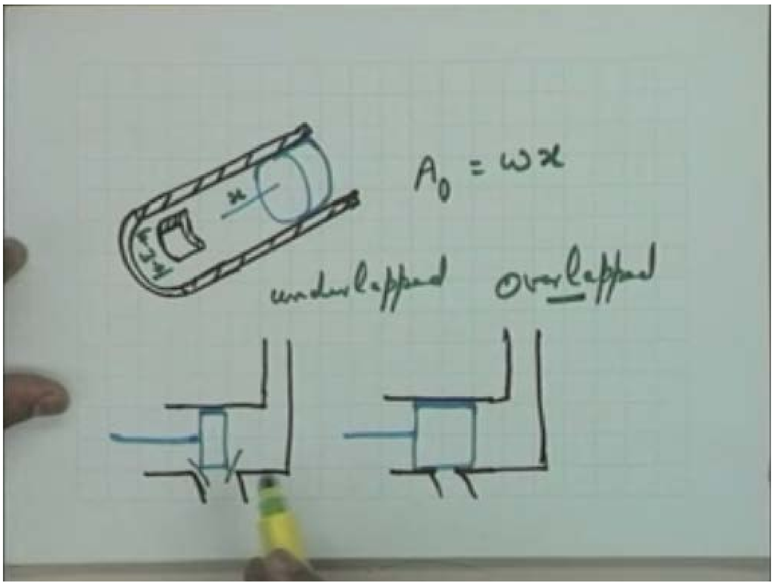

In this particular case the two types of constructions are possible. This particular construction as you will see (Refer Slide Time: 13:19) this is the spool land and this is the control port. This does not cover it fully and this particular construction is referred to as underlapped. This is in underlapped construction. In this particular case it covers it more than required and this is the overlapped construction. Both the constructions are in use.

Now let us see what are the problems with this construction. The problems with this construction is the sensitivity of the device or the dead zone of the device. you will please note that for small movements of these spool land there will not be any action because for small movements of the spool land this particular control port will not be covered or uncovered and therefore no action will be taken and therefore these systems or the motor or the linear actuator will be insensitive to small movements it will not take any action and in a typical feedback control situation you may not like that particular action that particular performance of the system; you will like that the motor comes into action as soon as there is a small movement of the spool which depends upon the error in the system. Therefore overlapped valves are normally not used in high precision control systems because of the in action state.

Now, underlapped valve are used and that they do work appropriately as will be seen. in this particular case since the slide is there before you I will show you this also; this shows that particular movement of the piston and this is the port (Refer Slide Time: 15:04). You will please note, movement of the piston and the port. so if i say that this width is W and this movement is let us say x in that particular case you will please note that W is a constant and the area covered or uncovered is directly proportional to x. Area of the port covered or uncovered is equal to A 0 let me say is equal to W into x where W is a constant. Once a particular port has been constructed W is a constant you are simply changing the x value. This particular picture I hope makes it very clear that the movement x is actually controlling the area open for fluid flow.

So now this slide need not come again if you remember if you keep this in mind if you just store this particular information in your memory. Keep this in mind that I will be using this information area is equal to W into x where W is the port width which is constant and I am going to use the underlapped valve. Come back to the previous slide which schematically shows the hydraulic motor (Refer Slide Time: 16:23). Now you see that in the neutral position you want x is equal to 0 and y is equal to 0. Help me, how can we achieve this objective with and under lap valve because you see that underlapped valve will allow movement of the fluid because this is the this is available this is open because of certain opening because of manufacturing tolerance or by design has been left and similarly this is also possible.

Let me just use a different color so that it makes it very clear. This movement is supplied to the cylinder you please note, supplied to the cylinder and this movement is cylinder to the port (Refer Slide Time: 17:09). Both these flows are possible and I really want that x is equal to 0 should give you correspondingly y is equal to 0. Please see that this is effectively possible in this particular case provided the leakage flow let me use the word leakage flow, because it is not the designed flow, so this particular flow in the neutral position is not the flow required for power action. So let me call it a leakage flow. If the leakage flow at this particular control port into the cylinder right hand chamber is equal to leakage flow out from the right hand chamber into the drain the y is equal to 0 condition is realized.

Similarly, you can see, if the leakage flow into the left hand chamber is equal to the leakage flow out of the left hand chamber under the steady state conditions, well, corresponding to x is equal to 0 it is y is equal to 0 and this is what happens. the leakage flow The oil is flowing all the time but the movement is like this only and hence the movement does not take place within the power cylinder and hence y is equal to 0 condition is realized.

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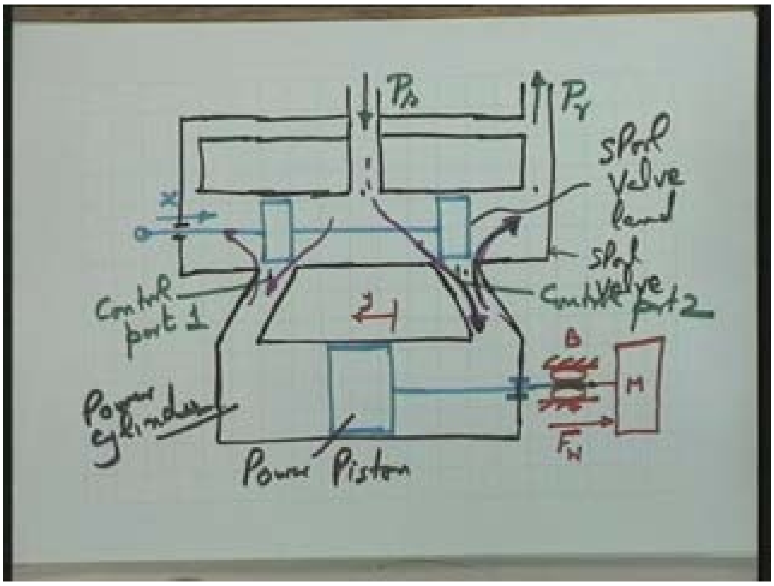

I am going to show to you that how this condition is realized, that is how this particular requirement is met that the leakage flow into is equal to leakage flow out of the power cylinder; right hand side chamber as well as the left hand side chamber and to prove this to you I will like you to recall the relationship of fluid flow through an orifice. You will please note that this is also a restricted fluid flow and we have already seen in our earlier discussion that a restricted fluid flow is governed by the orifice flow relation which is a nonlinear relation.

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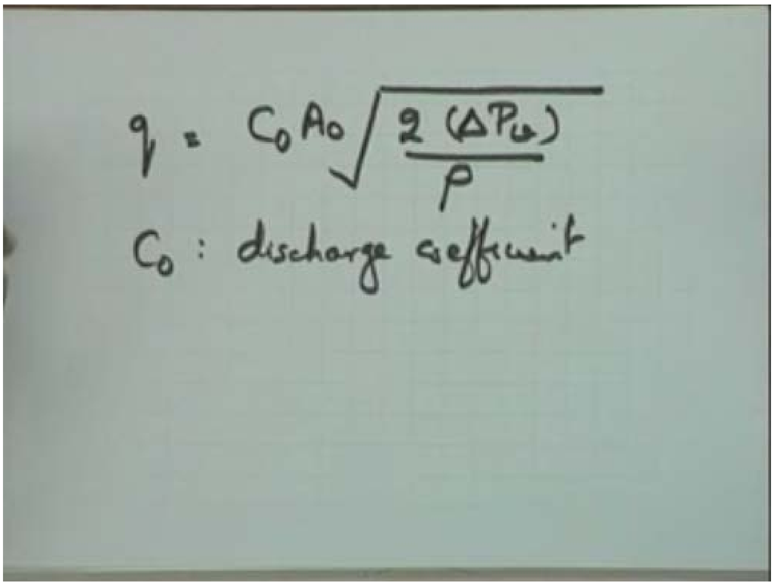

Well, I hope you will recall at list as soon as I write that relation: q is equal to the orifice fluid flow is equal to C 0 A 0 2(del P v) divided by rho. you can see that C 0 is discharge coefficient A 0 is the area open to flow, del P v is the pressure difference across the orifice in this case control port and rho is the density. This relationship we have already seen between q and the pressure across a port and this nonlinear relationship is there across this particular port as well.

Now, if I assume the pressure on this side to be P 1 (Refer Slide Time: 20:05) and the pressure on this side to be P 2 help me please, what is the pressure as far as this leakage flow into the system is concerned. It is P s minus P 1, I need your attention please; P s minus P 1 is the pressure as far as leakage into the chamber is concerned. Similarly, P 1 minus P r is the pressure as far as leakage out of the chamber is concerned. And you have seen the relationship; if these to pressures or equal the two flows will be equal and hence for the two flows to be equal my condition is this that P s minus P 1 should be equal to P 1 minus P r.

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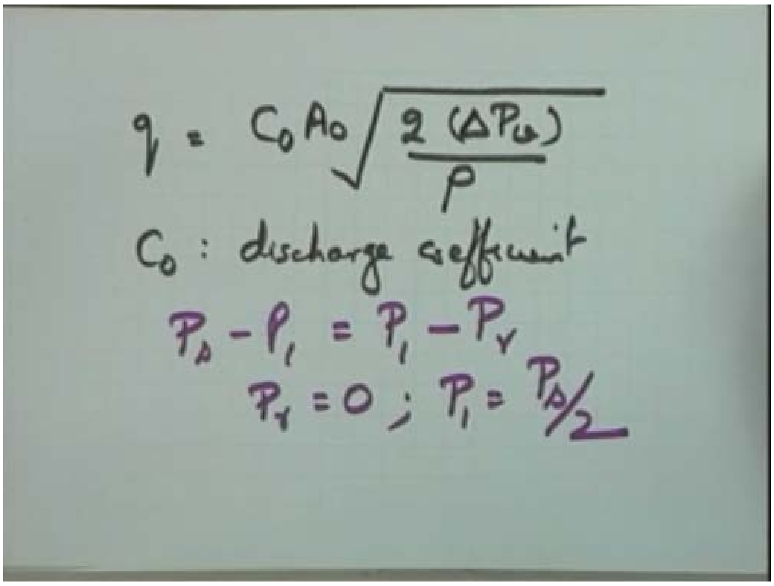

Having taken P r equal to 0 I get the relationship P 1 equal to P s by 2 and similarly you can convince yourself that at steady state P 2 will be equal to P s by 2 that is half the supply pressure at the steady state. This is the right hand side and the left hand side chamber pressures. So, having established the system working at the steady state now let me disturb the system. How do you disturb the system? You can disturb the system intentionally that is by movement of x that is, your commanded position will also change this particular ah change the system or perturb the system from the steady state or the system could be disturb by the disturbance force on this particular mass or the load. If a disturbance force acts here or the command changes over here the pressures P 1 and P 2 will change.

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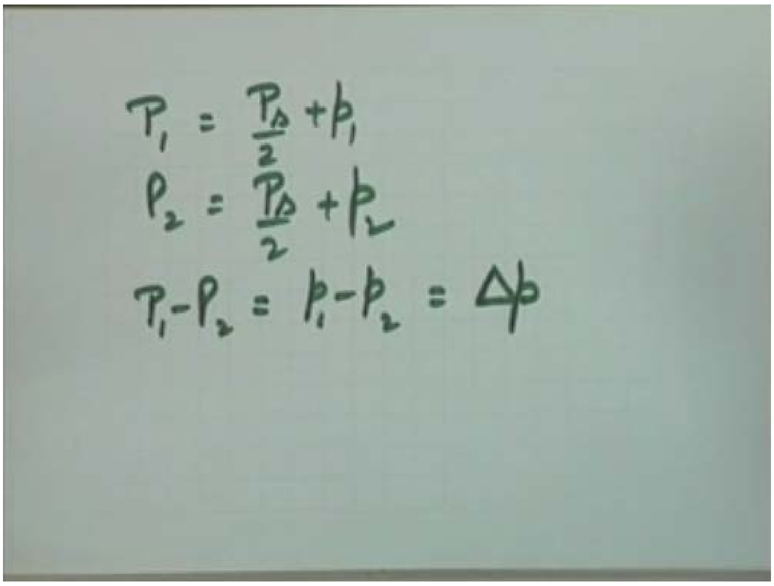

And let me say that the pressure P 1 becomes equal to P 1 pressure, what was the steady state please P s by 2 plus P 1 and let me say P 2 pressure is equal to P s by 2 plus P 2. Well, P 1 and P 2 both I am taking plus it simply means that these are algebraic quantities. Whether P 1 is greater than P 2 or less than P 2 depends upon the load induced pressures and the movement x you are going to give. So, for me P 1 and P 2 are algebraic quantities algebraic variables and I am taking to P 1 is equal to Ps by 2 plus P 1 and P 2 is equal to Ps by 2 plus P 2 so that the net pressure across the power piston is P 1 minus P 2 is equal to small p 1 minus small P 2 is equal to del p.

Now this del p is equal to 0 at steady state please note and this is the del p which will produce the required force to move the load. After all what is the force? The force is equal to pressure difference into the area of the piston that is going to be the force. So del p is an important variable I need your attention on this because this is the variable which is going to generate the force to move the load. A, the area of the power piston into del p is the force exerted on the load and this del p is equal to 0 at steady state and hence no force on the load and hence no movement. So this del p is the pressure difference across the piston.

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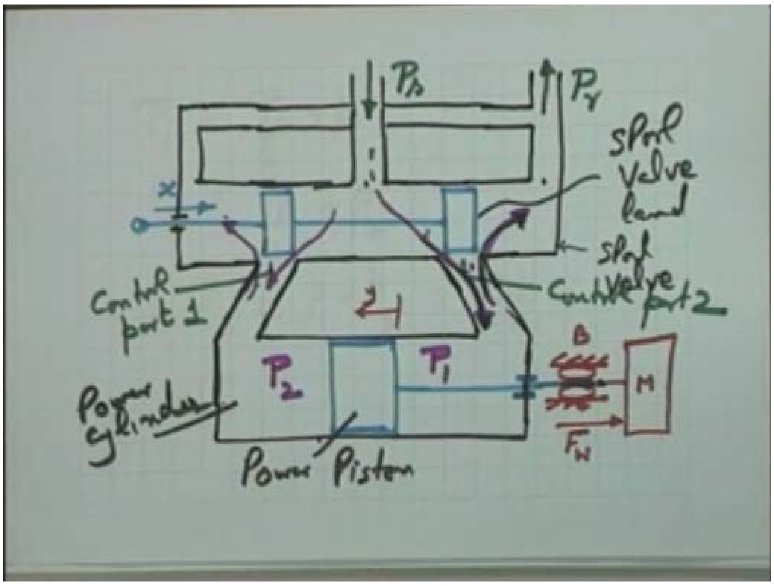

Coming back to this particular schematic diagram what is happening in this particular case please see: P s is the supply pressure and P r is the drain pressure. Can you account for the total pressure? Keep in mind that pressure is analogous to voltage if you use the concept of analogue. So you can apply Kirchhoff's voltage law to see the total voltage drop. So in this particular case I want you to travel along the root of fluid flow and keep the pressure drops in mind and give me the balance of pressure drops. So move along the fluid flow. You see that the net pressure difference, the fluid entering is at P s the fluid going out is at P r the net pressure difference is P s minus P r, account far that? This is a drop over here, there is a drop over here and there is a drop over here. So, if you travel through this particular root the net pressure difference is going to be equal to this drop plus this drop plus this drop, it means the supply pressure, this is obvious.

Please see that the supply pressure has to account for the pressure across the power piston. What is that pressure equal to? Please note that this pressure is equal to as demanded by your load because the force produce these going to be area into that pressure. So it means the supply pressure is also a design variable. You have to design that value appropriately. What are the requirements? the requirements do depend upon the load and the requirements depend upon the port construction because this supply pressure has to account for the pressure across the power piston and the pressure drops across the two ports and therefore I can write the pressure balance equation as: P s minus P r is equal to 2 into del P v plus del p, 2 into del P v plus del p.

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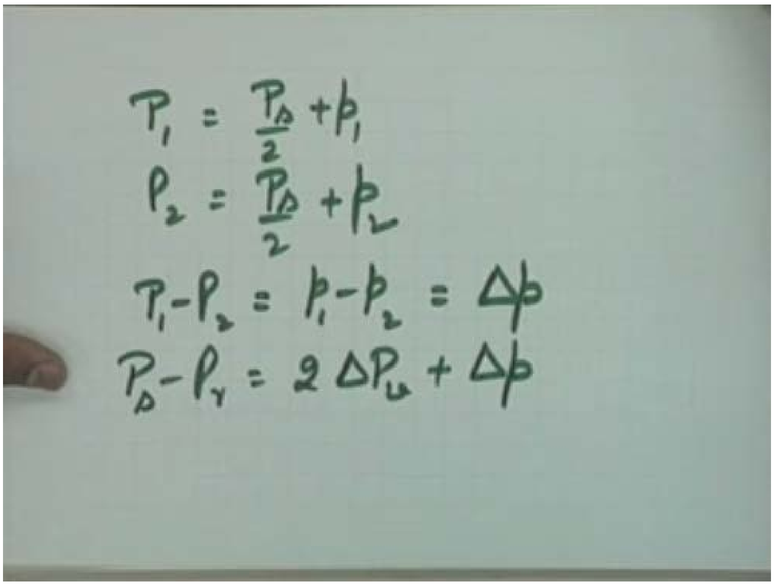

You will please note one point. In the process of writing this equation I am neglecting the leakage through this particular root (Refer Slide Time: 25:43) I am neglecting this leakage assuming that I have got suitable packings so that this particular leakage can be reduced to zero. So this leakage, I do not say that there will not be any tolerance. So, as you see, the tolerance has to be there for the movement but suitable packings are there which will reduce the leakage to a negligible zero amount and therefore for me P s minus P r becomes equal to 2 del P v plus del p.

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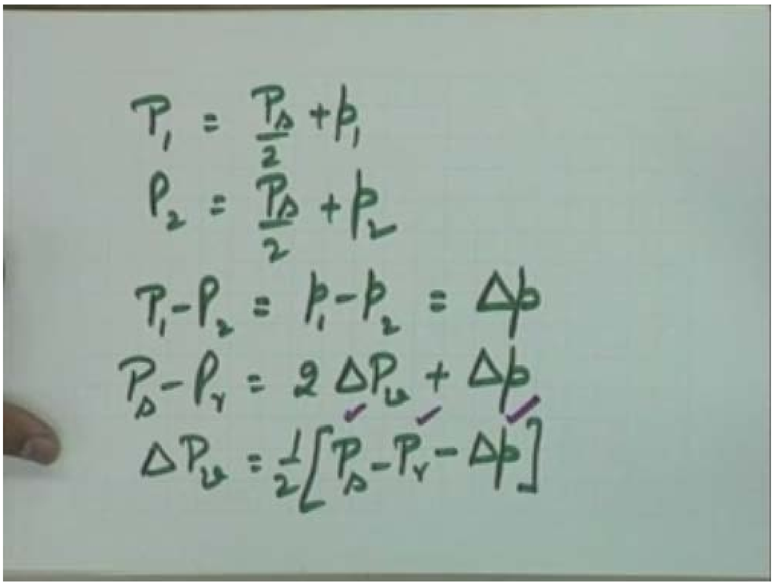

From this I get del P v equal to……… this is the relation I was interested in: P s minus P r minus del p del P r is close to atmospheric equation. This is an important point you see. I am going to make a very important statement on this relationship. So if any question is there on this relationship I like to answer that question.

What I want to say through this relationship is that the pressure drop across the port, once the system has been designed properly the pressure drop across the port is a function of del p because this P s and this P r gets fixed. If the pressure drop across the port is a function of del p….., what is del p? Del p is the load induced pressure. In that particular case you can write this relationship as: q equal to C 0 A 0 I am rewriting this 2 into del P v divided by rho. Please see that, if you permit, this relationship I am going to write as a function of x and del p all other variables of the system gets fixed.

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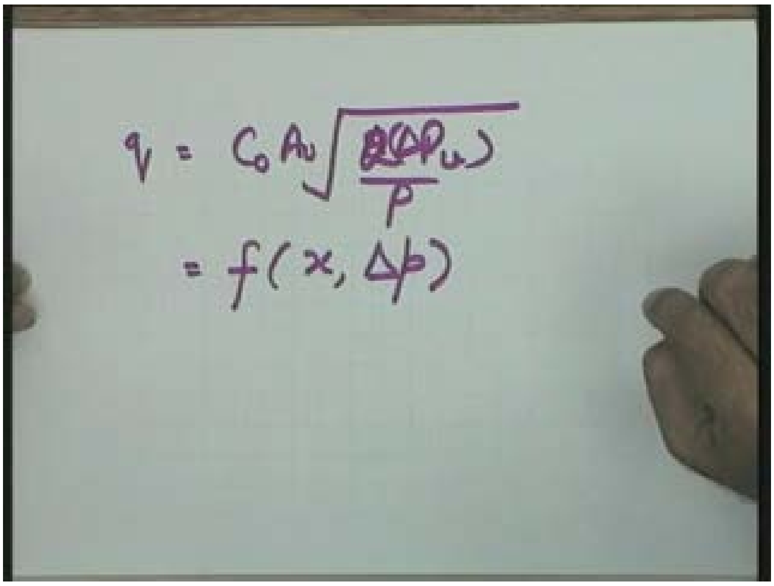

Please see your A 0 I told you to store that in your memory; A 0 is equal to W into x where W is the port width. So W is also a parameter which is fixed and therefore your q. The fluid flow into the power cylinder is a function of x the displacement of the spool valve and del p the pressure across the load piston pressure across the power piston.

What is the equilibrium point?
Please see, your equilibrium point is x is equal to del p is equal to 0. This is your equilibrium state. So it means, what you can do is if the perturbation is small, this is what we have been doing all through, around the equilibrium point if I take a small perturbation I will be able to get a linear model and the linear model will look like q is equal to K 1 sorry df by dx with respect to x if I take at this particular point into x minus df by d del p into del p with these derivatives evaluated at the equilibrium point.

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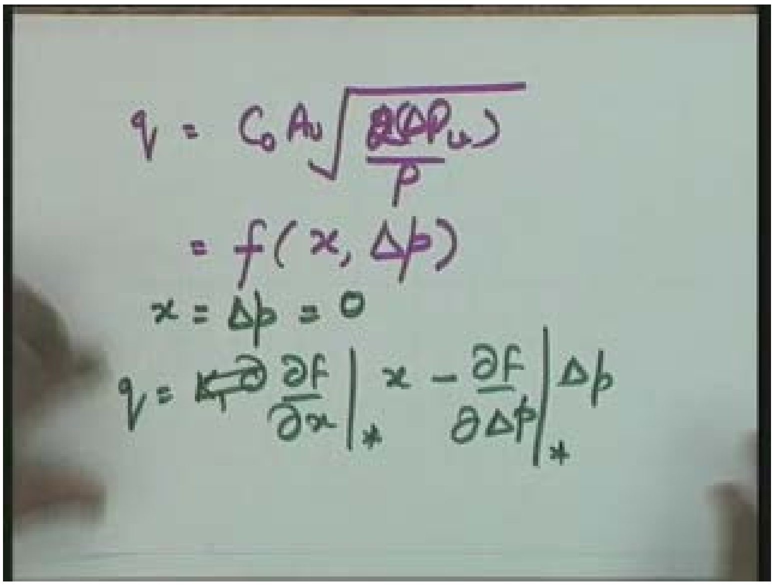

These derivatives are evaluated at the equilibrium point and therefore I get the relation: this is equal to K 1 x minus K 2 del p. The only thing is this that how to get the values of K 1 and K 2. Actually, in these hydraulic devices normally we go for experimental results to get the values of K one and K two. And if you see the manufacturers catalog you will find that experimental experimentally obtained characteristics of these devices are given by the manufacturer. So what you have to do is you have to suitably take the operating point on those characteristics and take the slopes K 1 and K 2 around those operating points. So those characteristics will be required. So, instead of giving you the total nonlinear characteristics let me take the linearized version.

After all I am going to make I have already made an assumption that the perturbation around the equilibrium point is small and therefore I am taking the linearized version of my characteristics. Any question please?
[Conversation between Student and Professor – Not audible ((00:30:12 min))]
Okay, that hopefully will become clear. I will keep that question in mind while explaining this. Del p is the pressure here and q is this particular fluid flow and here x is equal to 0 x is equal to minus x 1, x is equal to minus x 2, x is equal to plus x 1, x is equal to plus x 2. This is a running parameter because three three variables are involved: q the flow, del p the pressure difference across the port and x the movement of the spool.

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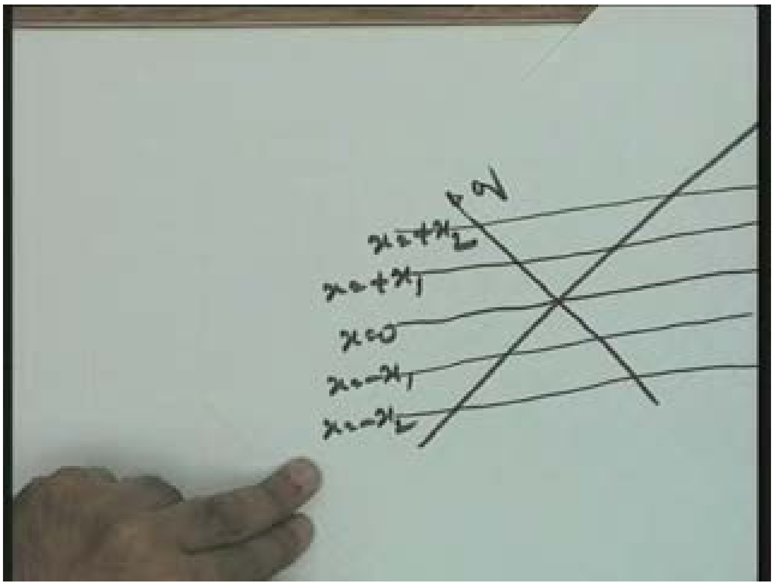

Now, in this particular case, you just see, the experimentally obtained characteristic, his question is answered because this slope is negative, this is the experimentally obtained curve. This is the slope here, is as you see, equal to K 2. If I take K two as a positive sign if numerically K 2 is taken as positive value in that particular case I will have to write this as minus K 2 does it answer your point please? The numerical value of K 2 will be plus. I would have written plus sign there but then that df by d del P would have given me a negative numerical value.

So, similarly, other slope if you take for constant pressure, let us say for a pressure del p is equal to 0 you take this and plot a curve q versus x and get the slope of q versus x and that value is K 1. So K 1 and K 2 are the two parameters; K 1 let me call it as the valve gain and K 2 let me call is the pressure coefficient if you like. So K 1 and K 2 are the two parameters of this particular model and I am going to use this relationship that the flow q is equal to K 1 x minus K 2 del p where K 1 and K 2 I give I reemphasize this point are normally obtained from experimental data supplied by the manufacturer. You simply fit your steady state point on that data, linearize around that steady state point and linearized curves will be of this nature and get the values of K 1 and K 2 from that particular information.

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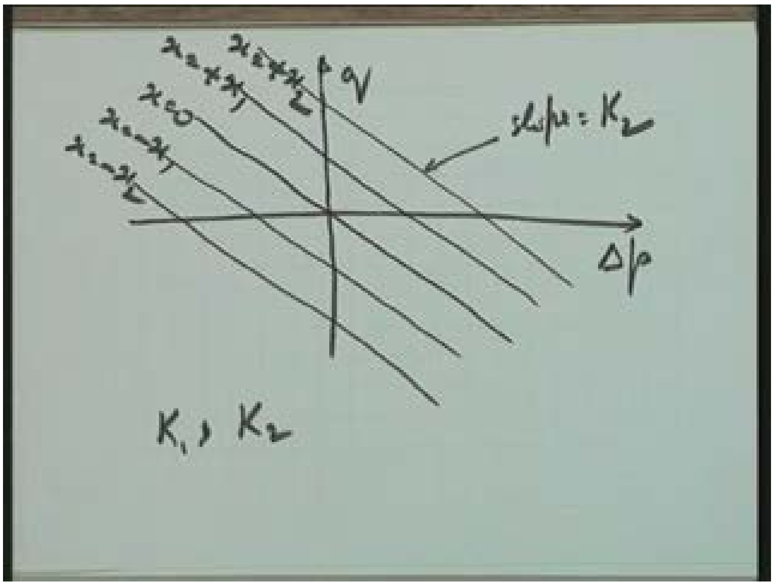

So if this is okay I think we are heading towards the completer model.

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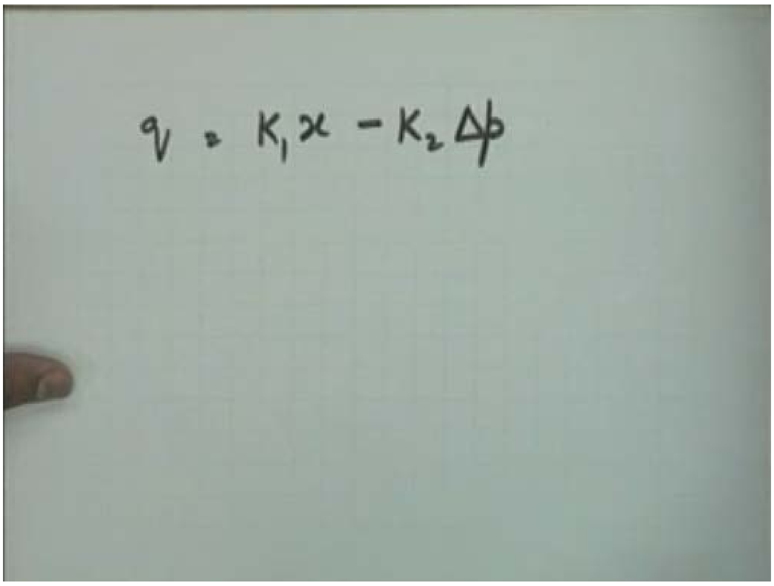

You have seen that q the flow into the power cylinder is equal to perturbation model of course. Now we are working over a limited region around the operating point around the steady state point. So q is equal to K 1 x minus K 2 into del p, fine?

Look at this schematic once again (Refer Slide Time: 33:02). What is this q equal to? This q is equal to the movement of the rate of movement of the fluid inside the cylinder which is going to be equal to, help me please, what is the movement? If I take this area as A, this is y, help me, what is the rate at which the fluid is moving in the power cylinder?

[Conversation between Student and Professor – Not audible ((00:33:30 min))]

Yes please, A is the area and q A y dot please see because it is going to be meter cube per second. q the unit, compatibility of units you should see; q is in meter q per second, a in meter square, y dot in meters per second so A y dot is going to be equal to the rate at which the fluid is moving into the power cylinder so let me call this as put this as A y dot.

Now let me write the force equation please: A into del p is the force developed due to the pressure del p and this force is going to move the inertia of the load against the friction and the disturbance. I repeat my point: It is going to move the inertia of the load which is M y double dot against the disturbance which I take B y dot and against the friction and the disturbance which I have taken as F W.

Now please get me a transfer function. Once this information is available you are equipped now to give me the transfer function. Keep in mind my interest is in two variables x and y; x being the input variable and y being the output variable. x will become my manipulated variable when I put this linear actuator into a feedback system and y is the controlled variable of the feedback system. So in this case if use this vary space so that these equations are available with me I start with the input variable straight away.

So the input variable is x, input variable is x; look at this point (Refer Slide Time: 35:18) so I am multiplying this by K 1 so I get this as K 1 into x to generate del p. You see, I want to generate del p so help me how do I generate del p; through the block diagram I will put it this way, I know that K 2 into del p is equal to K 1 into x minus A y dot. So it means let me put an error detector here and let this signal be coming from y dot and I put A block over here, I will see to it that this signal comes from y dot. So K 1 x minus A y dot if I take this variable this variable becomes K 2 into del p. I am interested in A into del p please see that I am putting over here A divided by K 2 (Refer Slide Time: 36:19) and hence a force variable is available here. I hope you are getting it well.

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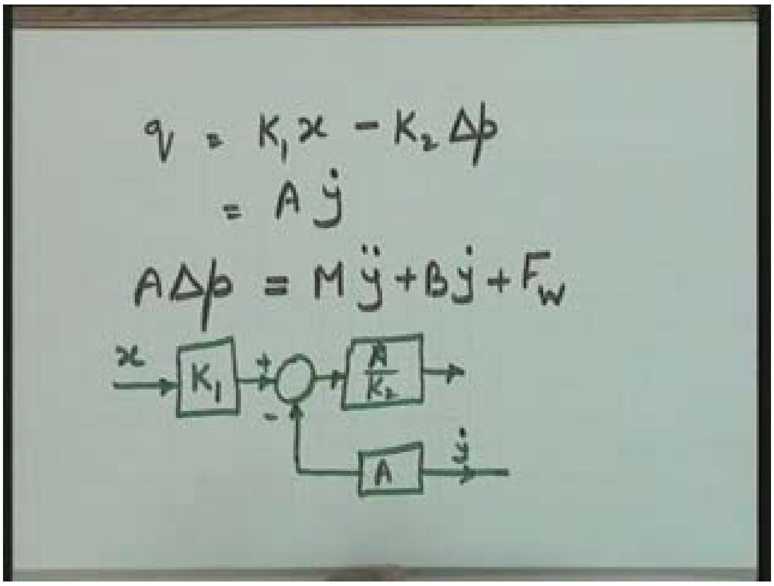

A force variable has come over here at this particular point because 1 over K 2 have K taken takes me gives me del p I have multiplied by A which gives me force. In the tutorial classes, please recall, you have not been taking compatibility of units into consideration that you have to keep in mind. I have the force variable let us say in Newton's so I can algebraically add Newton's to it and F W is a Newton's and therefore I can give the disturbance F W here. this is the net force to move the load and the net force move the load is going to be modeled like this: 1 over Ms plus B, this is your y dot y dot Ms plus B. Now you take this y dot and complete the feedback loop. Now this y dot as we have being doing earlier this is 1 over s here and the displacement y is available to you. This is the total picture.

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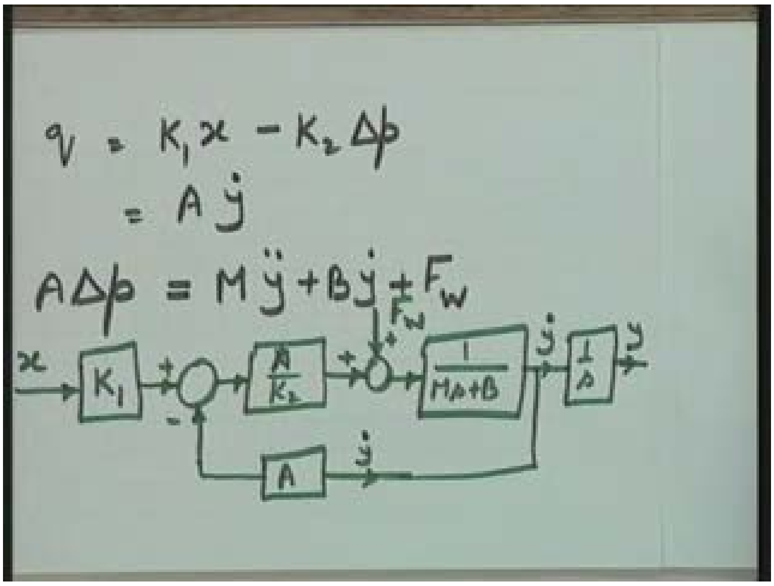

Now, if you take the transfer function model for this particular system the transfer function model between Y and X is of this form in terms of parameters. This, I leave to you to write it in terms of….. always represent your transfer function in terms of time constants or zeta and omega N depending upon whether the factor is a first-order factor or a second-order factor respectively.

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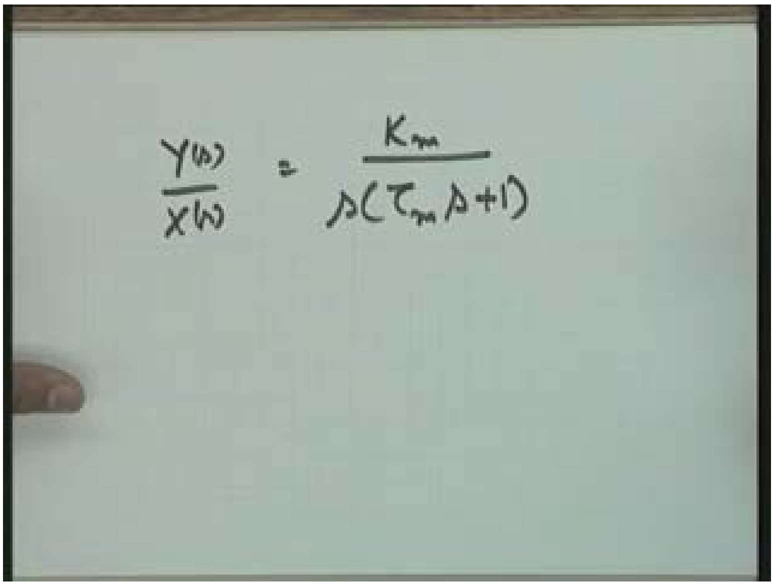

Since this is a first-order factor with in integrator I am putting the transfer function in the form: Y(s) over X(s) is equal to K m over s into (tau m plus 1). You can see that the transfer function is similar to that of a DC motor or an AC motor; the only thing is these that in this particular case tau m for the same size will turn out to be smaller and hence the hydraulic motor is normally faster compared to the corresponding electrical motor. Another point is that for the same size for the same horse power the size of the hydraulic motor is going to be small and therefore I again say that hydraulic motor is a very useful device for high power applications.

Now, before I give you an application you will appreciate my statement as soon as I give you applications, applications of numerical control, application of air craft control were hydraulic actuators are used but before that one more device I have to give you so that the total system can be explain to you and that device is a an electrohydraulic valve.

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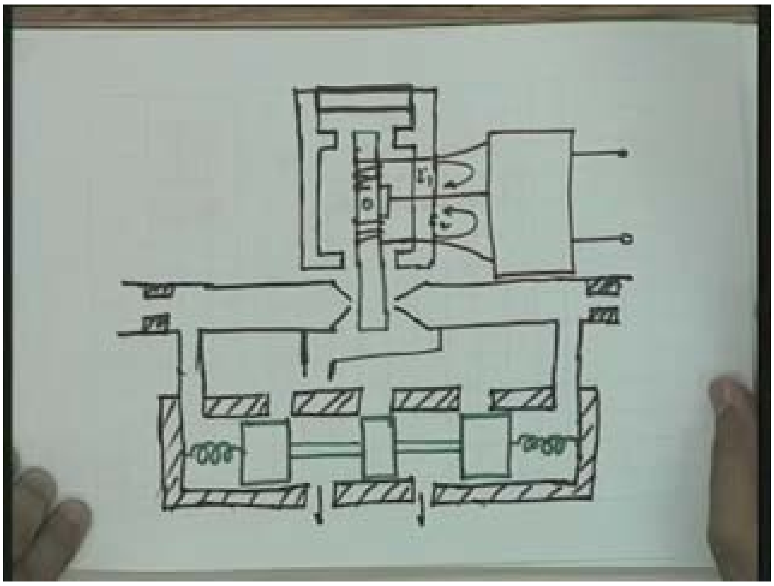

This device, I need your attention on this, this is an electrohydraulic valve. Now what is this valve and what is the purpose of this. As you will see, once you understand this particular device, the electrohydraulic valve is a very useful interface between an electronic controller and a hydraulic actuator. Please see that. I think, from the discussion we had so far we could conclude that in many applications you will require hydraulic actuator and not electrical if the requirements of power is high but if you go to the controller, recall what is a controller; amplifier only is not an is not necessarily a controller; in a control action you will require proportional action, derivative action, integral action or even more complex function.

Realizing these control functions through hydraulic equipment is difficult and is not even precise. So you see that when it comes to control you want to go for either a digital computer or Op-Amp based circuits and when you come to actuator you want to opt for a hydraulic actuator. So it means, really, there should be a suitable interface between the two, a suitable device which connects an electronic controller to a hydraulic actuator and this electrohydraulic valve is going to serve that purpose E-H valve in short. The purpose should be clear; a suitable interface between an electronic or digital controller and the load that is the actuator is necessarily required to be hydraulic because of the power requirement.

Well, I hope you will really understand this quickly because once you have seen that motor the action of this is not going to be difficult. This is your error e (Refer Slide Time: 41:19); once I talk of an electrical controller and electronic controller the error is going to be a voltage variable or a current variable. So let me take this e is the error; what is this error variable keep in mind; error variable is a representation of the deviation between the command and the actual action.

Whatever may be the variables of action; could be temperature, could be liquid flow, could be motion anything but e is representative of the error between what you have commanded and between what control variable is available to you and I assume that it is an electrical signal and particularly a voltage signal.

This voltage signal I give to a balanced amplifier. Now what this amplifier is going to do? It is going to do the following: when e is equal to 0 what will happen; the currents i 1 and i 2 are equal, the amplifier is designed that way that is all. The amplifier design I am not going to carry out here, I am going to give you the characteristics of the amplifier and I leave the amplifier design to you. When e is equal to 0 the two currents are equal, the two fluxes are equal and opposite and hence the net movement of this particular armature is going to be zero. I will show it here (Refer Slide Time: 42:47) this is a permanent magnet, this of course is an electromagnet and here this is an armature.

So what is the steady position?
The equilibrium position, naturally, when error e is equal to 0 you do not want any action to be taken because when error e is equal to 0 the load position follows the command position. So, if you do not want any action to be taken in that particular case this movement of this particular spool should be equal to zero and let us see whether that movement takes whether this situation is realized or not. these two currents are equal at the steady position, this armature does not move, if this armature is in exactly central position, you see that this is a flapper, this armature is acting as a flapper for these two nozzles; I need your attention along with drawing it, I mean the diagram will be available to you later also but look at the action please; these are the two nozzles; so this is acting as a flapper; so if these two distances are equal here is the supply pressure P s and here is the supply pressure P s so if these two distances (Refer Slide Time: 44:13) between the flapper and the nozzle are equal what will happen; the back pressure here P b and the back pressure here P b is going to be equal.

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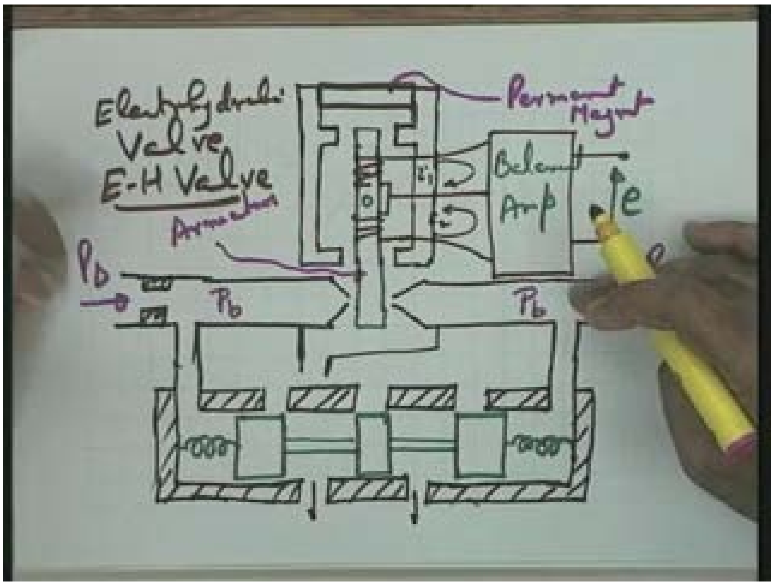

I hope this is very clear that you can control the pressure here by controlling this opening. If you move this flapper totally away, help me, what is the situation on P b; the P b will decrease or increase; if you move this flapper this particular flapper totally away from the nozzle, help me, intuitively what you say about P b? Will P b decrease or increase? Well, you have said both increase or decrease or clearly decrease?
[Conversation between Student and Professor – Not audible ((00:44:52 min))] Decrease, yes, quick please see, because this particular point is open to supply pressure the atmospheric pressure and if you close it P b goes towards supply pressure. So it means P b is changing between atmospheric pressure and supply pressure, atmospheric pressure is taken a zero gauge. In that case let me continue with this; the back pressures here are equal, now let us see e is positive. I want to convey to you that the movement of the spool is sensitive to the polarity and magnitude of e. If e is positive this should move it one direction, if e is negative in the opposite direction and the net displacement should be propositional to magnitude of e. This is what we want to have.

So, when e is positive one current is higher than the other and let me assume tentatively that the flapper movement is towards right. if the flapper movement is towards right what will happen; the back pressure here increases and there is now a net pressure available across this spool and therefore since the back pressure here is this high this spool moves in this direction. If the spool moves in this direction what will happen; this is your supply pressure (Refer Slide Time: 46:08) it means the oil is available here to one of the control ports and this is your drain and this is going out through the drain if you move it this way; this is a drain here and this is the supply pressure here.

I need your attention here. If this particular flapper moves right way this pressure is high, this moves in the left direction, if this moves in the left direction the control ports are getting the pressures this way, the supply pressure is available to this port and this port now is open to the drain. This, whatever I have shown is the drain because all those leakages from these two particular nozzles will go to the drain.

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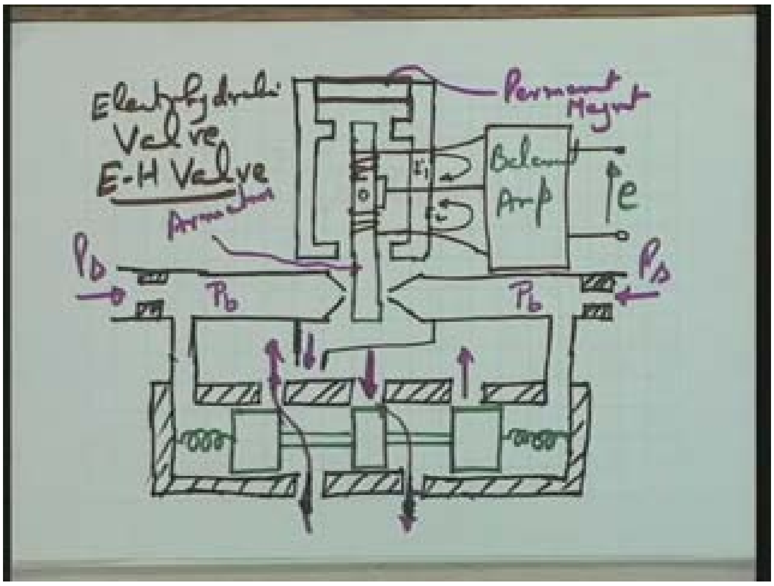

Well, the diagram is not complete from the point of complete construction. This is a drain, this is a drain, this is a drain so a common pipe can take it to the reservoir; it is only a schematic. The three points can be taken to the reservoir through a common pipe. This particular drain (Refer Slide Time: 47:14) is only to take care of the leakage; this point may be noted the leakage through this particular nozzles. So now you assume that the polarity of e changes. In that particular case this flapper this way and hence this pressure increases and hence this moves this way. Now if this moves in the opposite way let me use this color so in that particular case you can just see this pressure is available here and the drain is like this. If this moves in the opposite way this particular port gets connected to the high pressure line and this particular port is connected to the low pressure line. So this is what is the interface between the hydraulic actuator, the power cylinder and the electronic amplifier.

What I am going to assume is that the dynamics of this particular system is much faster than that of the actuator we are going to use and therefore a very simple situation for you, a big derivation is not coming. So I can assume that the displacement of the spool x is equal to a constant K into e where e is the voltage the error voltage the voltage supplied to the winding of the armature and x is the spool movement. This is I am considering, you please see the assumption. Not that it is not a dynamic device, there is dynamics but I am considering this to be a zero-order system assuming that the dynamics of this particular device it faster compare to this. Equivalently speaking time constant of the electrohydraulic device is much smaller than that of the motor and that is why we are neglecting it and we are going to take this to E-H valve as a zero-order device.

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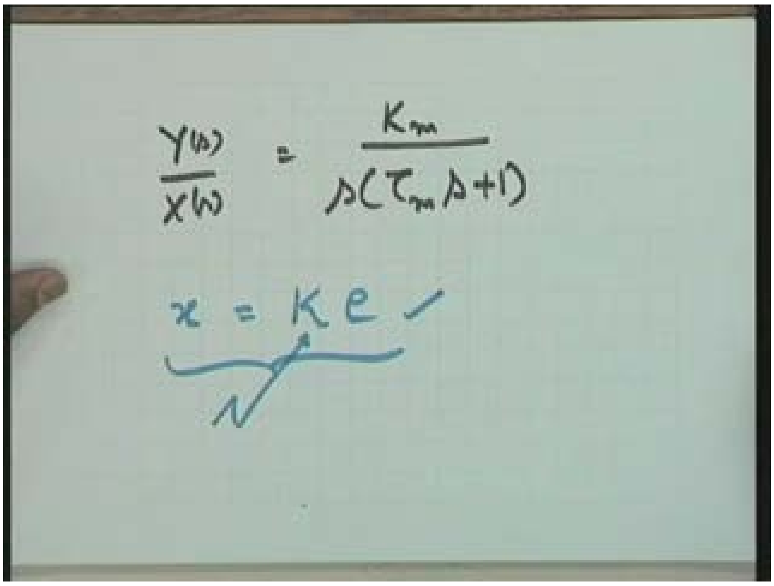

Thank you and next time I will take up feedback system using these devices.