Oil Hydraulics and Pneumatics
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Pump-controlled Hydraulic Systems
Lecture - 81
Part 2: Summary on hydrostatic drives, Power Transfer Unit (PTU), Pump controlled actuator system: Fixed-displacement, Pump controlled linear actuator system

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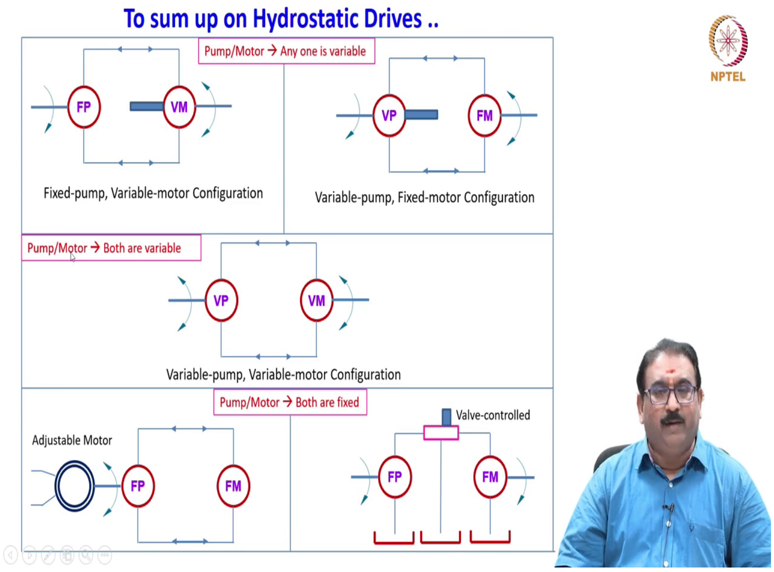

My name is Somashekhar, course faculty for this course. To sum up on hydrostatic drives, we have seen the many combination of pump bar motor. Here, pump bar motor any one is variable.

Look here, fixed-pump, variable-motor or variable-pump, fixed-motor. Pump and motor, both are variable, you will see here both are variable, variable-pump, variable-motor or you will see here last one, pump bar motor, both are fixed. You will see fixed-pump, fixed-motor, fixed-pump, fixed-motor.

But how I will get the different speed at the motor? By varying the input to the current input to the motor that is why I am writing here adjustable motor or through the valve controlled as I have told you know, you may use the flow control valves or anything to control the flow rate to the motor in case of both are fixed.

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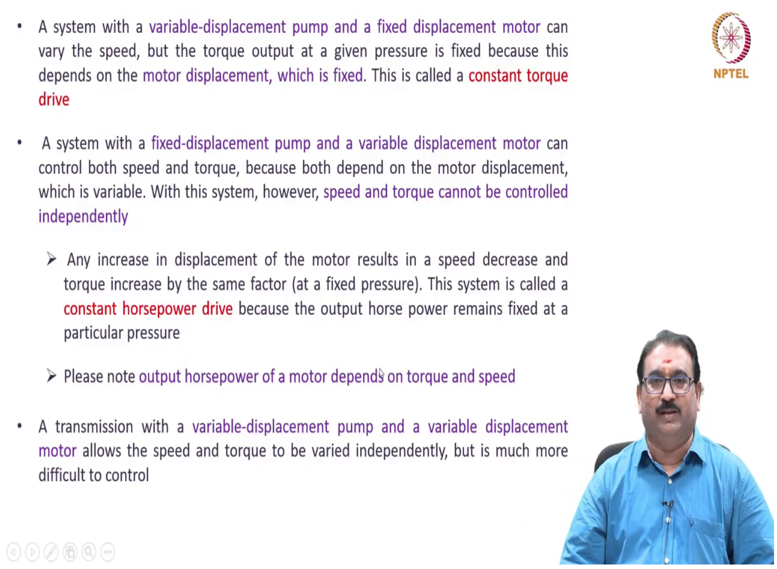

Also, we have seen a system with variable-displacement pump and a fixed displacement motor can vary the speed, but the torque output at a given pressure is fixed because this depends on the motor displacement, which is a fixed here we will see. This is called a constant torque; constant torque drive is variable displacement pump and fixed displacement motor combination.

Another one, a system with fixed-displacement pump you cannot change here now, and a variable displacement motor can control both speed and torque, because both depends on the motor displacement. Now, I am able to vary the motor displacement. So, with this system, however, the speed and torque cannot be controlled independently meaning what? One depends on the other.

Any increase in the displacement of the motor results in a speed decrease and torque increase by the same factor, at a fixed pressure. This system is called a constant horsepower drive because the output horse power remains fixed at a particular pressure. As because we know that the output horsepower of a motor depends on the torque and a speed. Power is a function of T and N.

A transmission with variable-displacement pump and a variable displacement motor allows the speed and torque to be varied independently; but is much more difficult to control. These are the some of the advantages and disadvantages of the pump bar motor combinations.

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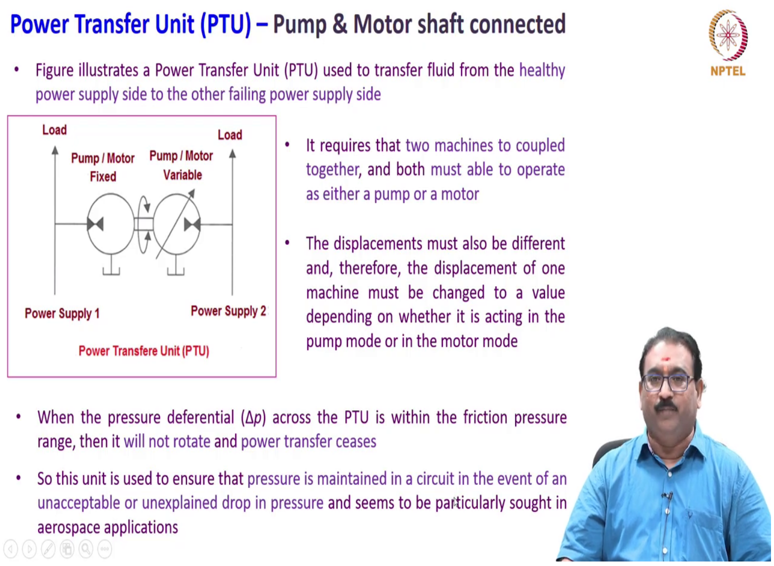

Now, sometimes we required one more device in the hydrostatic transmission what is known as Power Transfer Unit. It is briefly known as PTU. Here, pump and motor shafts are connected meaning what it is you will see here.

The figure illustrates a power transfer unit used to transfer fluid from the healthy power supply side to the other failing power supply side. You will see here friends, the pump bar motor unit, here pump bar motor unit, which is a variable, both are coupled here. Load may be different for the each.

It is required that the two machines to be coupled together and both must able to operate as either a pump or a motor. The displacement must also be different and therefore, the displacement of one machine must be changed to a value depending on whether it is acting in the pump mode or in the motor mode.

When the pressure differential across the PTU is within a friction pressure range, then it will not rotate and power transfer ceases. So, this unit is used to ensure that pressure is maintained in the circuit in the event of an unacceptable or unexplained drop in pressure and seems to be particularly sought in aerospace application. This PTU found a wide application in aerospace to maintain the constant pressures.

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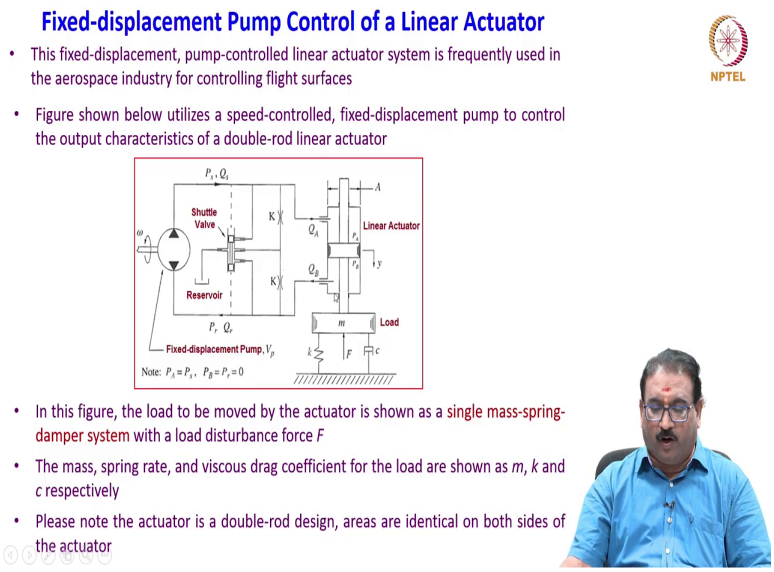

Now, we will see the quickly the analysis of the different units, pump bar motor unit first we will see the hydrostatic means as we know the pump is controlling the motor, but before that what we will do, pump controlled linear actuator how to model very quickly. Fixed displacement pump control of a linear actuator, this is the best example is controlling the two-rod symmetric double acting cylinders.

The fixed displacement, pump control linear actuator system is frequently used in the aerospace industry for controlling flight surfaces. This is the figure what I am showing you here, a figure shows below utilizes a speed-controlled, fixed displacement pump to control the output characteristics of the double-rod linear actuator. You will see here; this is a double rod linear actuator.

In this figure, the load to be moved by the actuator is shown as an single mass-spring-damper system with a load disturbances of the force is modeled as F. The mass, spring rate and the viscous drag coefficient for the load are shown in figure as m, k, c. Please note, the actuator is a double rod design meaning areas are identical here and there, then pressures are same please remember that is a beauty in the pump controlled linear actuator double rod sides.

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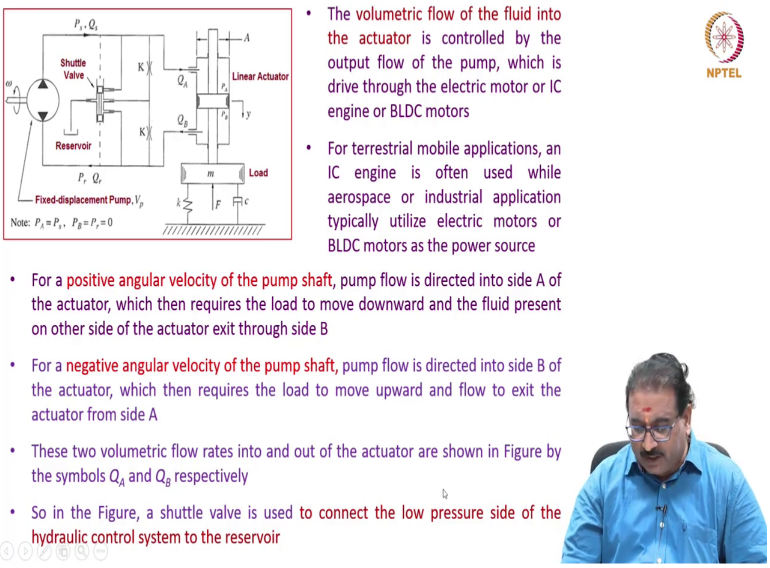

The volumetric flow; the volumetric flow of the fluid into an actuator is controlled by the output flow of the pump, which is drive through the electric motor or a IC engine or a BLDC motor motors, these are not shown here, I have shown here omega. For a terrestrial mobile applications, an IC engine is often used while aerospace or industrial application typically utilize a electric motors or BLDC servo motors as the power source.

For a positive angular velocity of the pump shaft pump, flow is directed into the side A, it is side B meaning the pump flow is coming Q A to the side A, then what happen? The piston will push the load downwards then whatever a fluid is here, it will go as a Q B, volumetric flow to the tank.

For a negative angular velocity of the pump shaft, pump flow is directed into the side B when it will rotate in the different direction, which is then requires the load to move upward and fluid flow to the exit from the A side; meaning it is you have to rotate the pump shaft to send the flow from one to other or other side to this, based on the pump rotation.

If it will rotate the clockwise, assume to be it will sucks the flow from the tank and delivers it here. If it is rotate in the reverse direction, it will do the other way. That is why it is directing the flow either to the B side or a A side based on the applications. These two volumetric flow rates into and out of the actuator are shown in figure by the symbols Q A and Q B respectively.

So, in the figure, a shuttle valve you will see here friends, a shuttle valve is used to connect the low-pressure side of the hydraulic controlled system to the reservoir.

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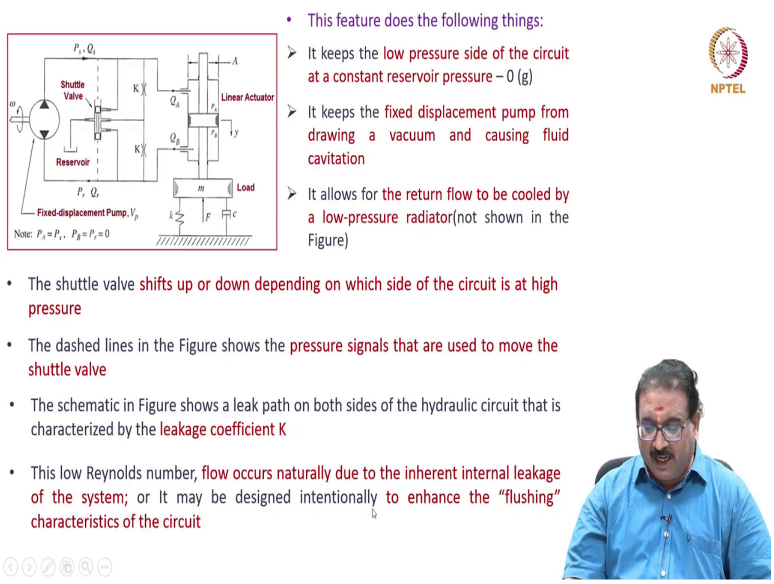

This feature does the following things, when we connecting the shuttle valve to the low pressure sides. It keeps the low-pressure side of the circuit at a constant reservoir pressure 0-gauge pressure. It keeps the fixed displacement pump from drawing a vacuum and causing a fluid cavitation.

It allows for a return flow to be cooled by the low-pressure radiator, radiators I am not shown here. The shuttle valve shifts up or a down depending on which side of the circuit is at the high pressure that is why the dashed lines are there know, which side you are moving the shuttle valve will matters based on the pressure side on either side.

The dashed lines in the figure shows the pressure signals that are used to move the shuttle valve. The schematic in figure shows a leak path on both sides of the hydraulic circuit that is characterized by the leakage coefficient K. This low Reynolds number, flow occurs naturally due to the inherent internal leakage of the system or it may be designed intentionally to enhance the flushing characteristics of the circuit.

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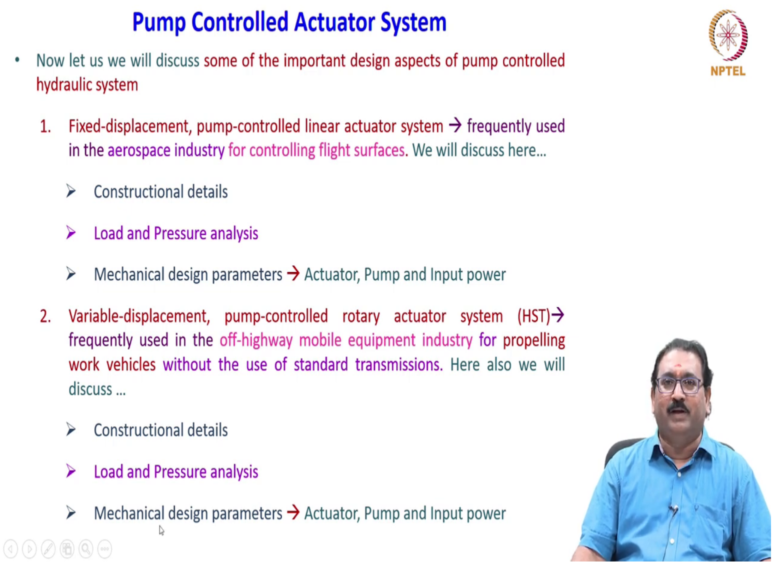

Now, we will move on to pump controlled actuator system. Now, let us we will discuss some of the important design aspects of pump controlled hydraulic system. Here, we will discuss 1st one, fixed displacement, pump controlled linear actuator system frequently used in the aerospace industry for controlling flight surfaces. We will discuss here, constructional details, load and pressure analysis, mechanical design parameters particularly, the actuator, the pump and the input power.

Next one is variable displacement, pump controlled rotary actuator system. As I have already told it is a hydrostatic transmission frequently used in the off-highway mobile equipment industry for propelling work vehicles without the use of standard transmissions. Here also, we will discuss constructional details, load and pressure analysis, mechanical design parameters particularly for actuator, pump and input power.

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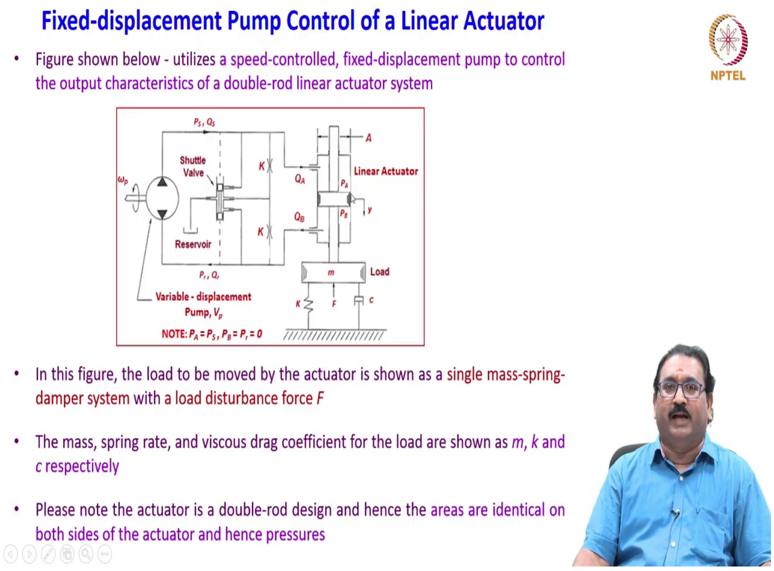

Let us we will move one by one. First one is fixed displacement pump controlled linear actuator. Figure shown below utilizes a speed controlled, fixed displacement pump to control the output characteristics of a double-rod linear actuator system. Please see friends here, it is a variable displacement pump, and it is a linear actuator system.

Here, I have marked various things here, the pressure is P S and Q S is a flow which is going to the side A, this is the side A and this is the side B. When the flow is going here, the Q A it will push, then whatever the flow is there at the side B, it will go as a Q B to the adding to the pump inlet.

Here also, we will see friends here, the load is shown here m and other parameters like spring and damper are shown with k and c. Let us we will see now, how this will work. In this figure, the load to be moved by the actuator is shown as a single mass spring damper system with a load disturbance low force F.

In this figure, the load to be moved by the actuator is shown as a single mass spring damper system with a load disturbance force F. The mass, spring rate and viscous drag coefficient for the load are shown as m, k and c respectively. Please note, the actuator is a double-rod design and hence the areas are identical both sides of the actuator and hence the pressures.

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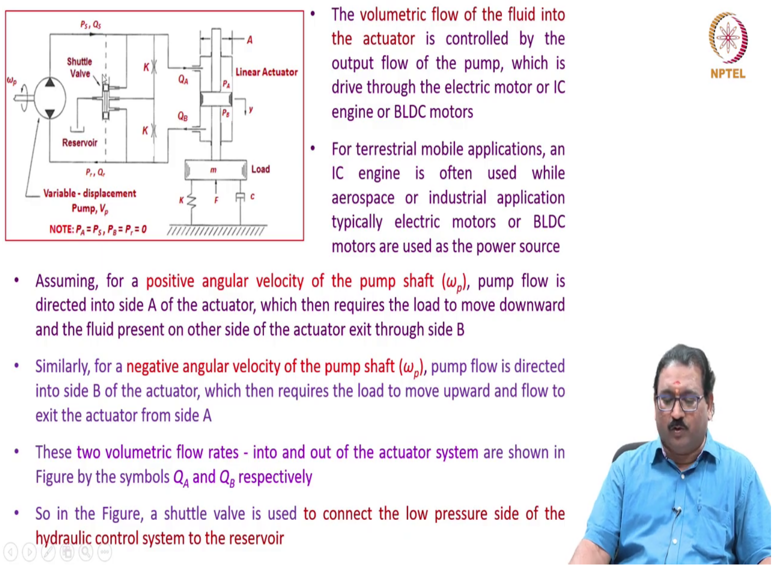

The volumetric flow of the fluid into the actuator is controlled by the output flow of the pump, which is drive through the electric motor or a IC engine or a BLDC motor. For a terrestrial mobile applications, an IC engine often used while aerospace or industrial application typically a electric motors or a BLDC motors are used as a prime source to drive the pump.

Assuming, a positive angular velocity of the pump shaft omega p, pump flow is directed into the side A of the actuator, which then drives the load to move downward and the fluid present on the other side of the actuator exit through side B. Similarly, for a negative angular velocity of the pump shaft, pump flow is directed into the side B of the actuator, which then requires the load to move upward and the flow present at the A side will exit the actuator from the A side.

These two volumetric flow rates Q A and Q B that is a into and out of the actuator system are shown symbolically as Q A and Q B respectively. So, in the figure, a shuttle valve is used to connect the low-pressure side of the hydraulic system to the reservoir.

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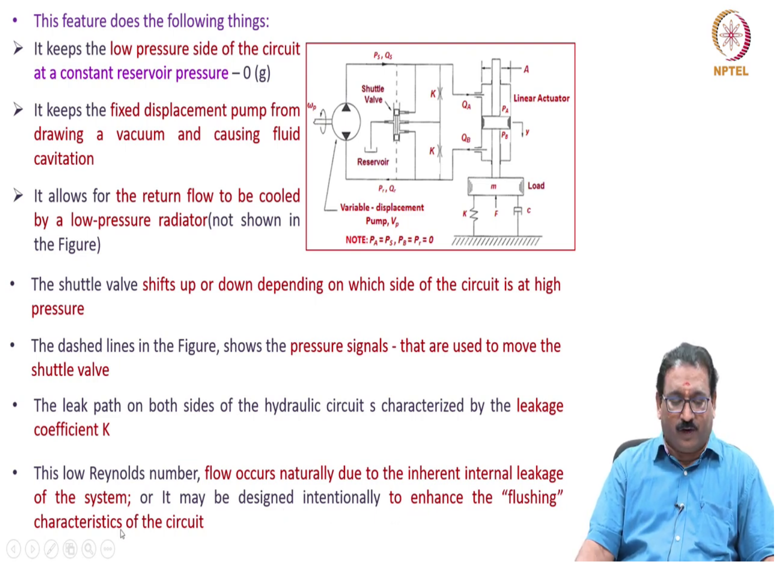

This feature does the following things: it gives the low-pressure side of the circuit at a constant reservoir pressure 0-gauge pressure. It keeps the fixed displacement pump from drawing a vacuum and causing a fluid cavitation. It allows for the return flow to be cooled by the low-pressure radiator. Here, I have not shown here.

The shuttle valve shifts up or down depending on which side of the circuit is at high pressure. The dashed line here shows the pressure signals that is used to move the shuttle valve up and down. The leak path on both sides of the hydraulic circuit is characterized by the leakage coefficient K. Flow occurs naturally due to the inherent internal leakage of the system or it may be designed intentionally to enhance the flushing characteristics of the circuit.

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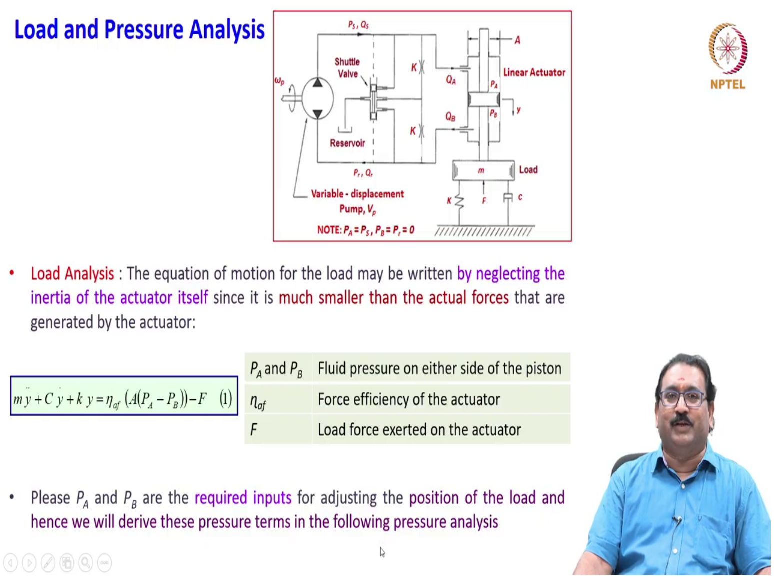

Now, let us we will see the load and pressure analysis. The equation of motion for the load may be written by neglecting the inertia of the actuator itself since it is much smaller than the actual forces that are generated by the actuator. So, m y double dot plus C y dot plus k y is equal to this is a the force efficiency of the actuator multiplied by the force A into P A minus P B minus F. Let us we will call this is an equation number 1.

Please note, P A and P B are the required inputs for adjusting the position of the load and hence, we will derive these pressure terms in the following pressure analysis.

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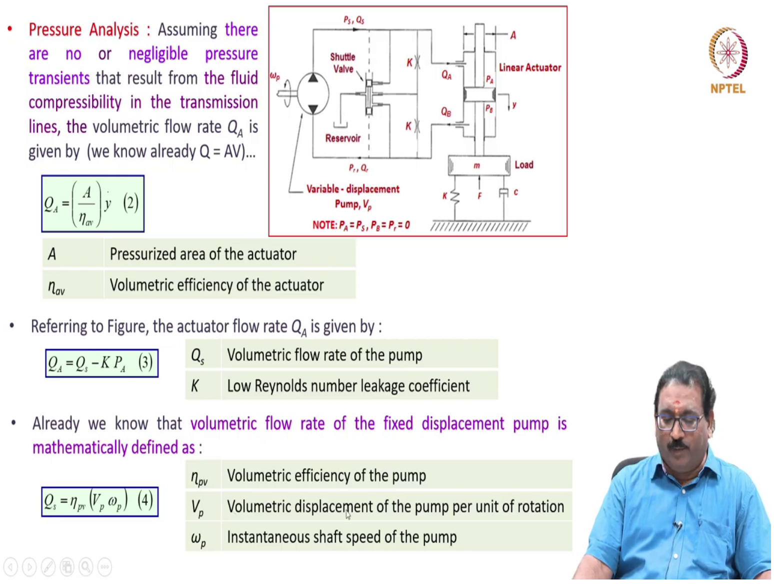

Assuming there are no or a negligible pressure transients that results from the fluid compressibility in the transmission lines, the volumetric flow rate Q A is given by already we know that Q A equal to A into V. So, using this Q A equal to A divided by volumetric efficiency of the actuator multiplied by y dot. We will call it as equation number 2.

Referring to the figure, the actuator flow Q A is given by Q A equal to you will see here, Q S minus K into P A, call it as equation number 3. Here, Q S is a volumetric flow rate of the pump and K is already we know that low Reynolds number leakage coefficient. Already we know that the volumetric flow rate of the fixed displacement pump is mathematically written as Q S equal to volumetric efficiency of the pump multiplied by V p into omega p.

Where V p is a volumetric displacement of the pump per unit rotation, omega p is the instantaneous shaft speed of the pump.

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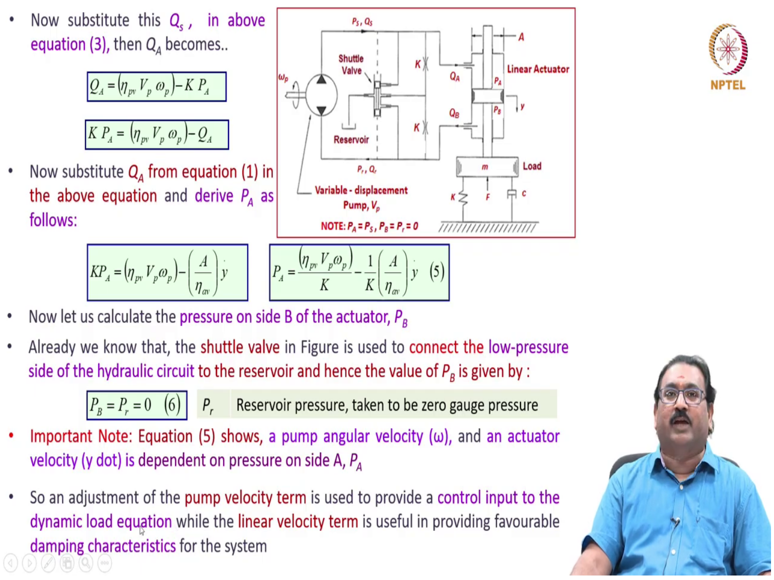

Now, substitute this Q S in the above equation 3, then Q A becomes Q A equal to this. Then, what we will do now? Now, I will take this term here K P A equal to this term, this minus Q A will go here. Now, I will substitute Q A here, now what we will do? This Q A from the equation 1, we will substitute here because our objective is to determine the P A and P B.

Now, P A; KP A equal to I am substitute in Q A equal to A divided by this, then P A equal to divided by the K here correct friend, we can call it as very important equation pressure at the side P called it as equation number 5. Now, let us calculate the pressure B on the side B known as P B.

Already we know that, the shuttle valve in figure is used to connect the low-pressure side of the hydraulics circuit to the reservoir and hence the value of P B is given by P B equal to P r that is equal to 0. P r is the reservoir pressure taken as the zero-gauge pressure. Important note here, you will see here from the equation 5, P A equation, the pump angular velocity omega and an actuator velocity y dot is dependent on the pressure at side A.

So, an adjustment of the pump velocity term is used to provide a control input to the dynamic load equation while the linear velocity term is useful in providing a favorable damping characteristics of the system.

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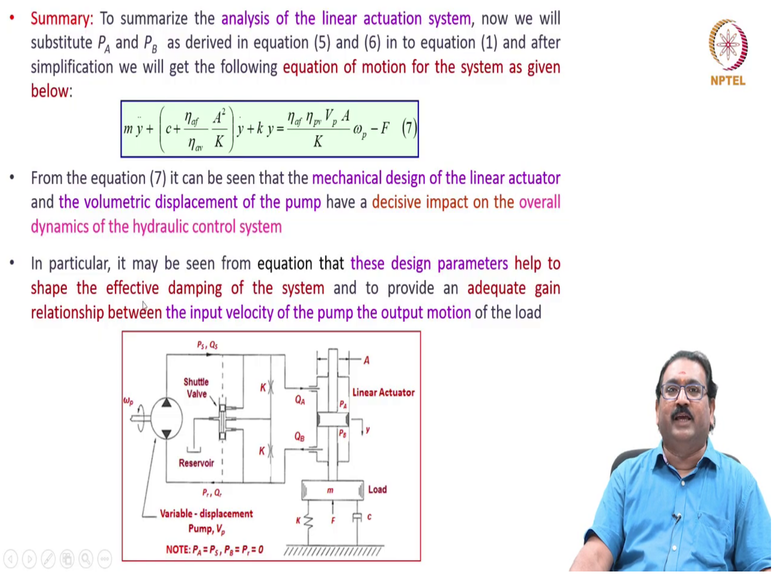

Summary here, to summarize the analysis of the linear actuation system, now we will substitute P A and P B as derived in equation 5 and 6 in equation 1 and after simplification, we will get the following equation of motion for the system as given below. I am substituting the P A and P B term here.

From the equation 7, it can be seen that the mechanical design of the linear actuator and the volumetric displacement of the pump have a decisive impact on the overall dynamics of the pump controlled hydraulic system. In particular, it may be seen from the equation that these design parameter help to shape the effective damping of the system and to provide an adequate gain relationship between the input velocity of the pump the output motion of the load.

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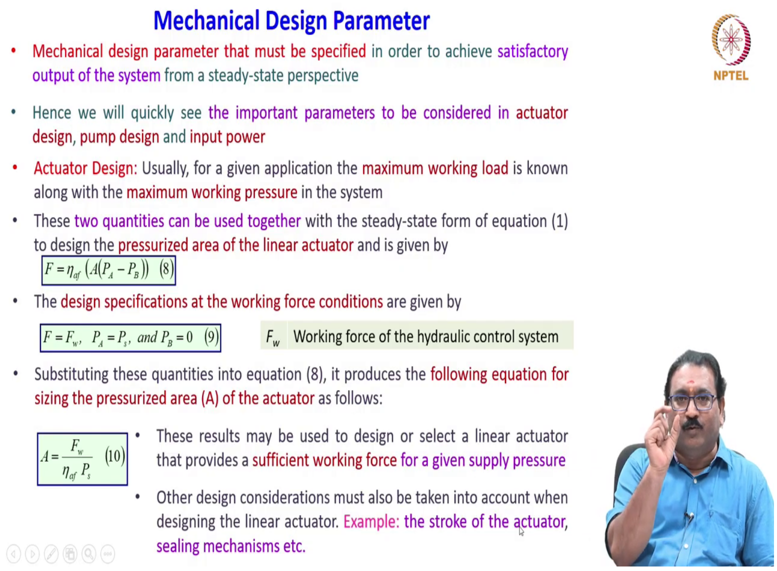

Now, let us we will see some of the important parameter like a mechanical design parameter as I have told you, we will see the some of the important parameters particularly to the actuator, pump and input power here. Mechanical design parameter that must be specified in order to achieve a satisfactory output of the system for a steady state perspective. Hence, we will quickly see the important parameters to be considered in actuator, design pump design and a input power.

Actuator design, usually for a given application the maximum working load is known along with the maximum working pressure in the system. These two quantities can be used together with the steady-state equation as shown in the above equation number 1 to design the pressurized area of the linear actuator and is given by F equal to the efficiency the force efficiency of the actuator multiplied by again force A into P A minus P B, we can call it as equation number 8.

The design specifications at the working force conditions are given by F equal to F w, P A equal to P s and P B equal to 0 where, F w is a working force of the hydraulic control system. Substituting these quantities into equation 8, it produces the following equation for sizing the pressurized area A of the actuator as follows: A equal to F w by nu af into P s, you call it as equation number 10.

These results may be used to design or select a linear actuator that provides a sufficient working force for a given supply pressure. Other design considerations must also be taken into account when designing the linear actuator. Example, the stroke of the actuator, how much it will move in extension as well as retraction and a sealing mechanism provided, these are also very important.

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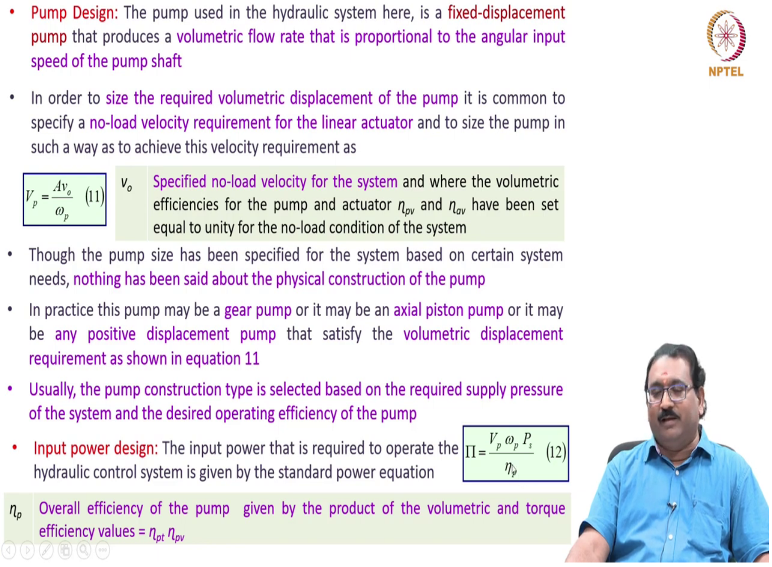

The pump design, the pump used in the hydraulic system here is a fixed displacement pump that produces the volumetric flow rate that is proportional to the angular input speed of the pump shaft. In order to size the required volumetric displacement of the pump, it is a common to specify a no-load velocity requirement for the linear actuator and to size the pump in such a way as to achieve this velocity requirement as V p equal to A v naught by omega p.

v naught is the specified no-load velocity for the system and where the volumetric efficiency of the pump and actuator nu pv and nu av have been set equal to unity for the no load condition of the system. Though the pump size has been specified for the system based on certain system needs, nothing has been said about the physical construction of the pump.

In the practice, this pump may be a gear pump or it may be an axial piston pump or it may be any positive displacement pump that satisfy the volumetric displacement requirement as shown in figure 11. Usually, the pump construction type is selected based on the required supply pressure of the system and the desired operating efficiency of the pump.

Then, we will move onto the input power design, the input power that is required to operate the hydraulic control system is given by the standard power equation pi equal to V p omega p into P s divided by the nu p where nu p is overall efficiency of the pump which is given by the product of the volumetric efficiency and the torque efficiency. Here, I am representing nu pt into nu pv.