Oil Hydraulics and Pneumatics

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Part 4: DAC-Effective area, force, velocity, acceleration and deceleration, Performance characteristics, Telescopic cylinder and its application

Lecture - 54

Hydraulic Cylinders

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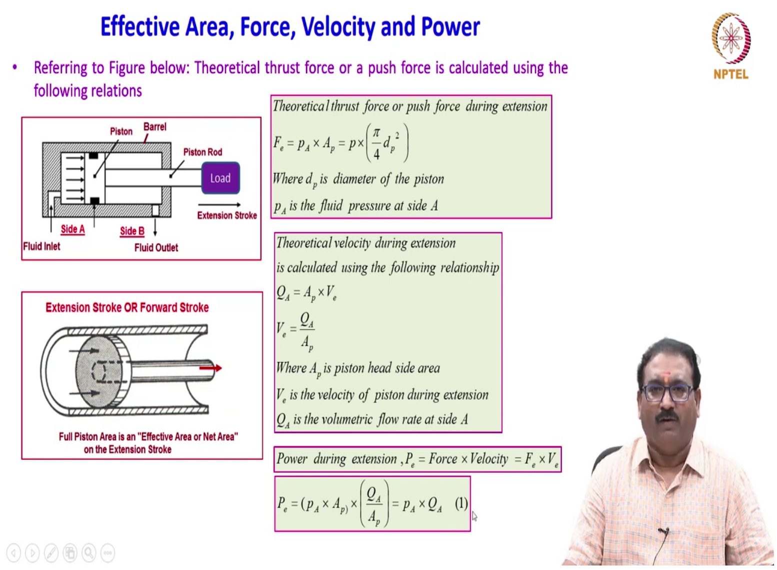

My name is Somashekhar, course faculty for this course. Now, let us we will see the Effective area, force, velocity and power in the cylinders. Referring to figure below theoretical thrust force or a push force is calculated using the following relations. Just you will see here friends the load is pushing through the fluid pressure. Pressure is acting on the head side over the piston surface area. See here piston surface area is an effective area over which fluid is acting.

Therefore, the push force during the extension is calculated using the pressure acting at the side A multiplied by the area over which it acts that is a pi by 4 d p square d p is the diameter of the piston and p a is the fluid pressure at side A. Similarly, the theoretical velocity during extension is calculated using the following relationship.

As we know Q equal to A V. Using that Q A equal to A p into V e, where V e is a Q A by A p. A p is the piston head side area and V is the velocity of the piston during the extension, Q A is the volumetric flow rate at side A. The power during the extension P e is calculated using the force into velocity.

F e during extension multiplied by the velocity during the extension. After substituting the value we will get the power during the extension is p A into Q A. Let us we will call this equation number 1 for the power during the extension stroke.

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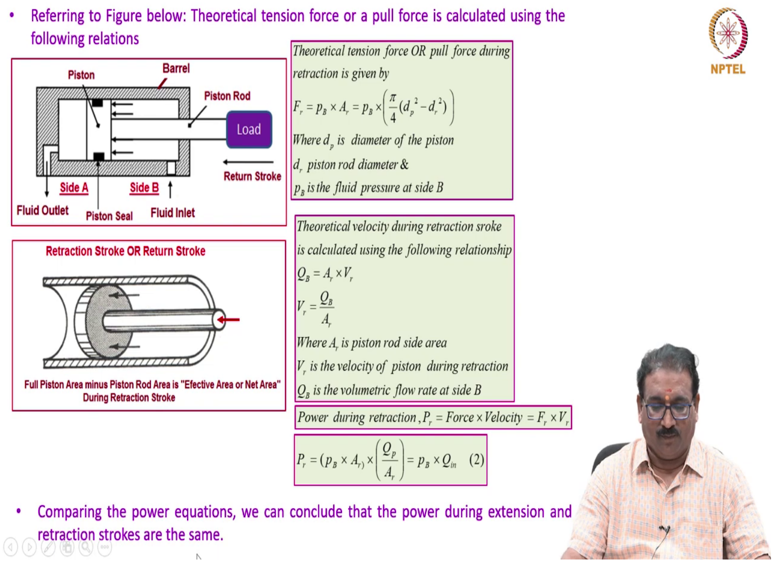

Similarly, let us we will see the theoretical tension force or a pull force using the following relations here. Now, we will see friends now here the pressure is acting on the tail side ok here tail side. Then you will see the effective area is the piston diameter minus the rod diameter.

Now, we will see the theoretical tension or a pull force during the retraction is given by p B into A r. p B is the fluid pressure at side B and A r is the area over which it acts during the retraction, which is given by pi by 4 d p square minus d r square. Similarly, the theoretical velocity during the retraction is calculated using the following relations; Q B equal to A r into V r, where we want V r.

V r equal to Q B by A r, where Q B is the volumetric flow rate at side B and A r is the piston rod side area. Then the power during the retraction is the force into velocity. After substituting these two equations here we will get p B equal to Q en, this is for the during the retraction. By comparing the two power equations for the extension as well as retraction what happens? The power during the extension and retraction strokes are the same.

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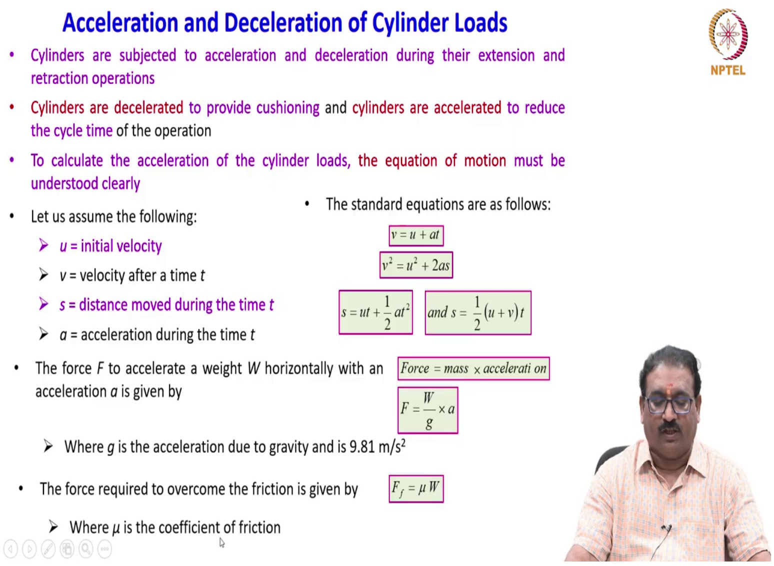

Now, we will see the acceleration and deceleration of a cylinder loads. Cylinders are subjected to acceleration and deceleration during extension and retraction operations. Cylinders are decelerated to provide a cushioning and the cylinders are accelerated to reduce the cycle time of the operations.

To calculate the acceleration of the cylinder loads the equation of motion must understood clearly. Let us assume some of the parameter. u equal to initial velocity, v equal to velocity after a time t, s equal to distance moved during the time t, a is acceleration during the time t.

Then the standard equations as we know all the v equal to u plus a t and v square equal to u square plus 2 as. Then s equal to ut plus half a t square and s equal to half u plus v into t. Therefore the force F to accelerate a weight W horizontally with an acceleration a is given by force equal to mass the mass into acceleration that is a W by g into a.

Then where g is the acceleration due to gravity and is given by 9.81 meters per second square. The force required to overcome the friction is given by F of f equal to mu into W, where mu is the coefficient of friction.

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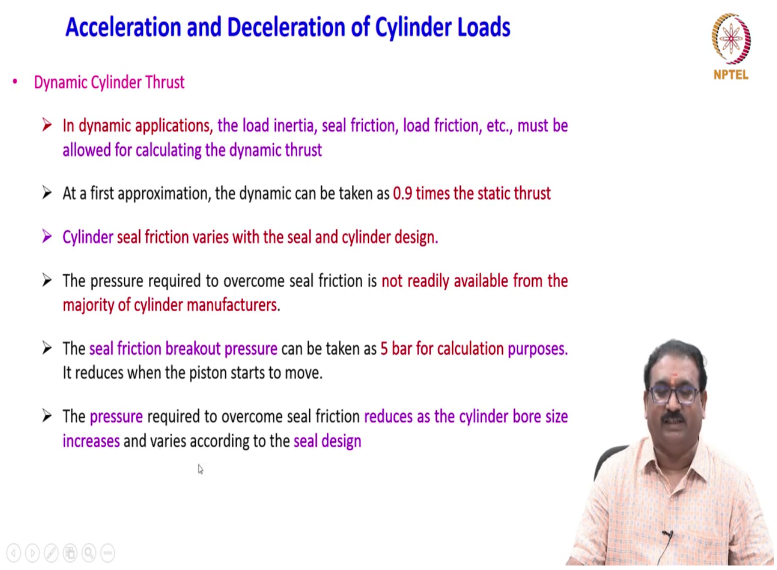

Now, dynamic cylinder thrust: in dynamic application the load inertia, seal friction, load friction, etcetera must be allowed for calculating the dynamic thrust. At a first approximation the dynamic can be taken as 0.9 times the static thrust. Cylinder seal friction varies with the seal and a cylinder design. The pressure required to overcome the seal friction is not readily available from the majority of the cylinder manufacturers.

The seal friction breakout pressure can be taken as 5 bar for calculation purposes. It reduces when the piston starts to move. The pressure required to overcome the seal friction reduces as the cylinder bore size increases and varies according to the seal design.

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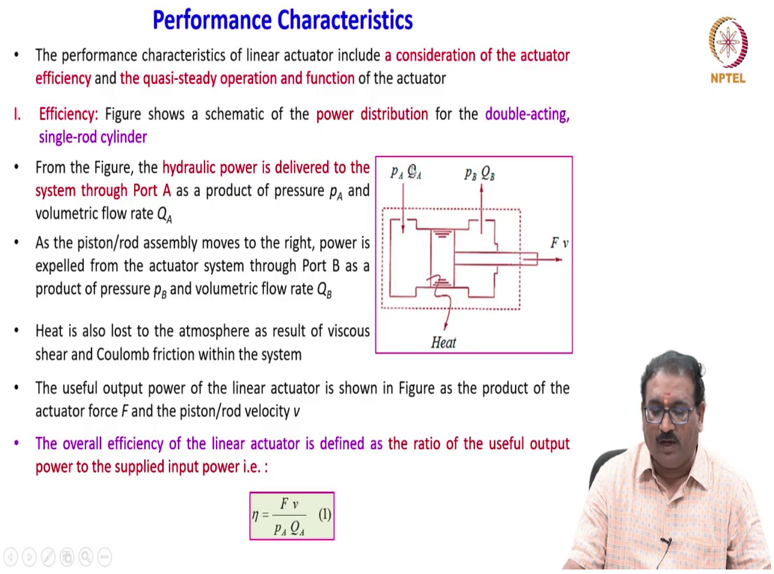

Now, we will see the performance characteristics of the cylinders. Here we are discussing the various types of efficiencies. The performance characteristics of a linear actuator include a consideration of actuator efficiency and the quasi steady operation and a function of the actuator. Let us we will see first efficiency.

Now, figure shows a schematic of power distribution for a double acting cylinder single rod type. You will see here the figure from the figure the hydraulic power is delivered to the system through a port A, this is a port A as a product of pressure times and volumetric flow rate. Correct here? This is a the hydraulic power hydraulic power delivered to the left side meaning the port A is p A into Q A.

As the piston or a rod assembly moves to the right power is expelled from the actuator system through a port B as a product of pressure p B and a volumetric flow rate Q B. Heat also lost to the atmosphere as a result of viscous shear and a Coulombs friction within the system. The useful output power of the linear actuator is shown in the figure as a product of force into the velocity, the rod velocity.

The overall efficiency of the linear actuator is defined as the ratio of the useful output power to the supplied input power. Here is a output power and this is an input power which is the ratio efficiency is F into v divided by p A into Q A because it is a input here, this is an output.

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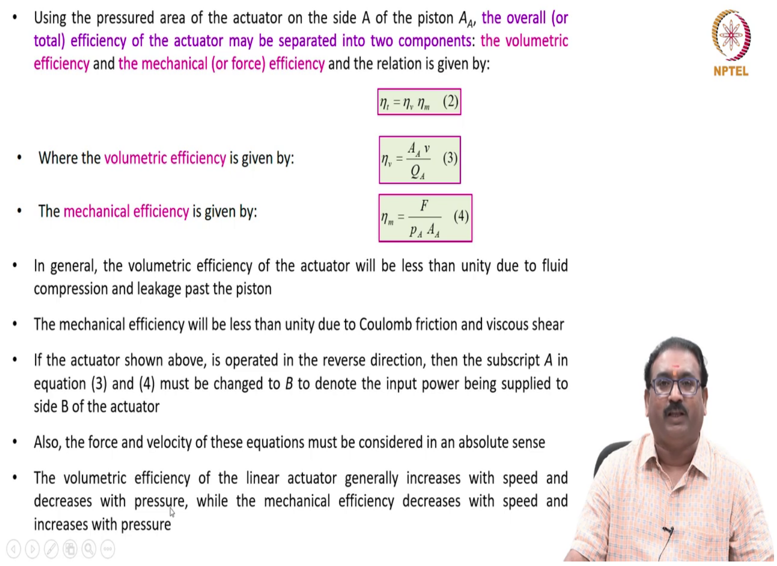

Using the pressure area of the actuator on the side A of a piston A A, the overall efficiency of the actuator also known as the total efficiency of the actuator maybe separated into two components; the volumetric efficiency and the mechanical efficiency or sometimes it is known as force efficiency also and the relation is given by volumetric efficiency into mechanical efficiency is the total efficiency.

Where volumetric efficiency is given by A A into v divided by Q a. Similarly, the mechanical efficiency is given by F divided by p A into A A. In general the volumetric efficiency of the actuator will be less than the unity due to the fluid compression and a leakage past the piston. The mechanical efficiency will be less than the unity due to the coulomb friction and a viscous shear.

If the actuator shown above is operated in the reverse direction meaning in the retraction stroke then the subscript what I have mentioned here A is replaced by the subscript B to denote the input power being supplied to the side B of the actuator. Also the force and velocity of these equation must be considered in the absolute sense.

The volumetric efficiency of the linear actuator generally increases with the speed and decreases with the pressure while the mechanical efficiency decreases with the speed and increases with the pressure.

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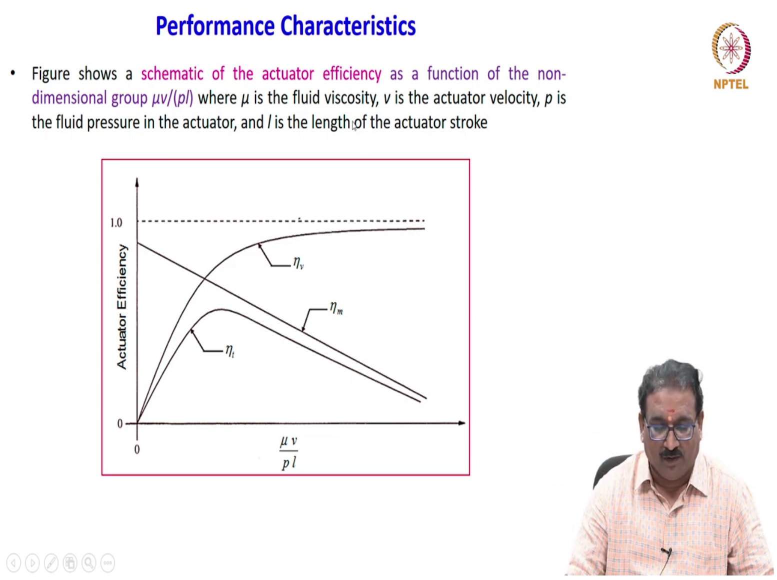

Now, we will see I have shown you the performance characteristics of the double acting cylinder. The y axis is the actuator efficiency and a x axis is a non dimensional group mu v by p l, where mu is the fluid viscosity and v is the actuator velocity and p is the fluid pressure and l is the length of the actuator stroke.

You will see here what I have shown here volumetric efficiency how it is goes on increasing with respect to the non dimensional value what I am taken here. Similarly, the mechanical efficiency decreasing. This is the total efficiency by adding these two I am getting here taking the difference. This is a the total efficiency derived from multiplying the volumetric efficiency into mechanical efficiency.

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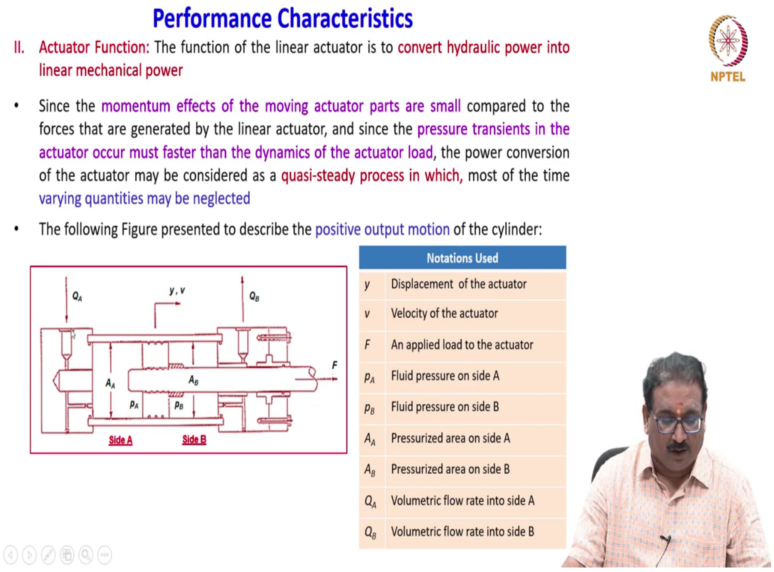

Now, we will see the actuator function. The function of the linear actuator is to convert the hydraulic power into linear mechanical power. Since the momentum effect of the moving actuator parts are small compared to the forces that are generated by the linear actuator and since the pressure transient in the actuator occur must faster than the dynamic of the actuator load, the power conversion of the actuator may be considered as a quasi steady process in which most of the time varying quantities may be neglected.

See here this is the following figure represented to describe the positive output motion of the cylinder. Here you will see I have represented some of the terminologies. Here you will see this is a piston, piston rod which is having the two side it is a cushioning then this is a head side and this is a tail side.

Here for the convenience I am taken the side A as the head side, side B is a tail side. Here y into y, v I am written know, here is a displacement of the actuator and v is the velocity of the actuator. Similarly, the F is the an applied load to the actuator how much you are applied here. And p A is the fluid pressure on side A and p B is the fluid pressure on the side B. And A A is the what it is?

The pressure area on the side A, A B is the pressure area on the side B. Similarly, Q A and Q B are volumetric flow rate into the side A and side B.

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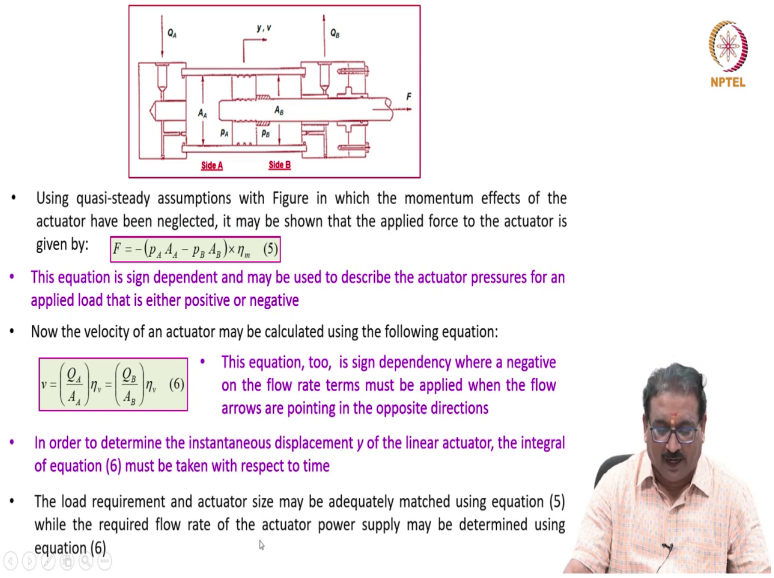

Now, we will see now here using the quasi steady assumptions with figure in which the momentum effects of the actuator have been neglected, it may be shown that the applied force to the actuator is given by minus p A into A A minus p B into A B multiplied by the mechanical efficiency. This I will call it as equation number 5.

This equation is a sign dependent and may be used to describe the actuator pressures for an applied load that is either positive or a negative. Now, the velocity of the actuator may be calculated using the following equation. Q A by A into volumetric efficiency; similarly Q B by A B into volumetric efficiency. I will call it as equation number 6.

This equation 2 a sign dependency where a negative on the flow rate terms must be applied when the flow arrows are pointing in the opposite directions. In order to determine the instantaneous displacement y of the linear actuator the integral of equation 6 must be taken with respect to t. The load requirement and the actuator size may be adequately matched using the equation 5 while the required flow rate of the actuator power supply may be determined using the equation 6.

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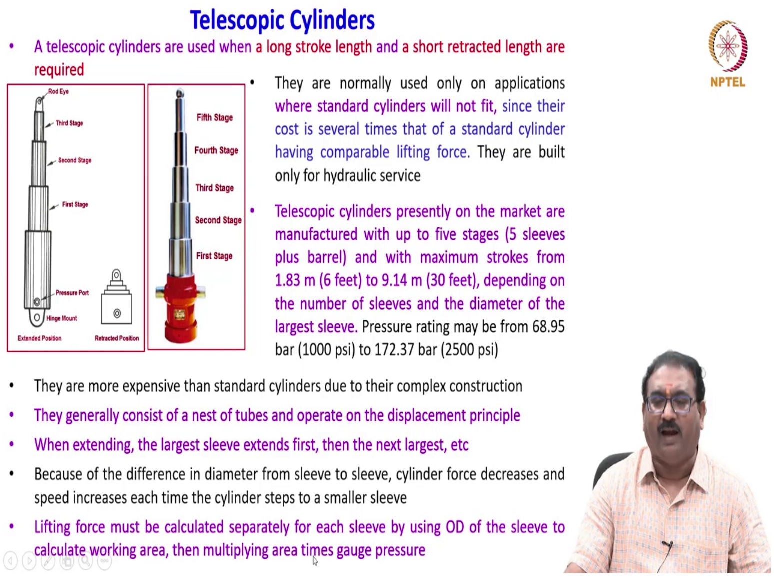

After knowing the performance characteristics of the double acting cylinder let us we will see now some of the special actuators for the special purposes. The mainly I am discussing now onwards some of the spatial actuators meant for the pneumatic applications, but these are also used in the hydraulics. Telescopic cylinders, you will see friends what is this telescopic cylinders.

By seeing the figure itself it tells us that the one sleeve inside the other. You will see it is a retracted position of the telescopic cylinder. In the extended position you will see first stage, second stage, third stage. Up to how many stage? Up to five stages of the sleeve will extend with the fluid pressure. A telescopic cylinders are used when a long stroke length and a short retracted length are required.

They are normally used only on applications where a standard cylinders will not fit, since their cost is several times that of the standard cylinder having a comparable lifting force. They are built only for hydraulic service. Telescopic cylinders presently on the market are manufactured with up to five stages; meaning 5 sleeves plus the barrel and with a maximum strokes from 1.83 meter to 9.14 meter, depending on the number of sleeves and the diameter of the largest sleeve.

The pressure ratings may be from 68.95 bar to 172.37 bar. They are more expensive than the standard cylinders due to their complex construction. They are generally consists of a nested tubes and operate on the displacement principle. When extending the largest sleeve extends first, then next largest, like this they are goes on extending.

Because of the difference in diameter from sleeve to sleeve cylinder force decreases and speed increases each time the cylinder steps to a smaller sleeve. Lifting force must be calculated separately for each sleeve by using the outside diameter of the sleeve to calculate the working area, then multiplying area times the gauge pressure.

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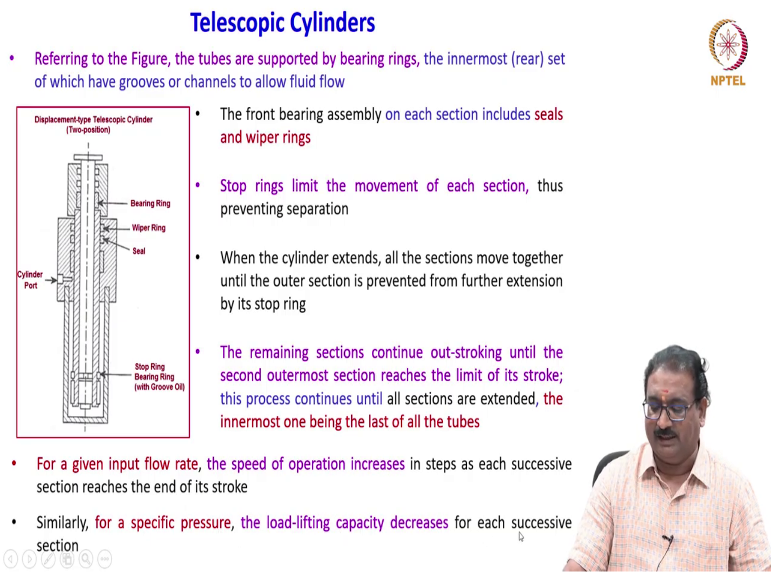

You will see the constructional features of the telescopic cylinder. Referring to the figure, the tubes are supported by a bearing rings, the innermost set of which have a grooves or a channels to allow the fluid flow. Here you will see friends neatly displacement type of telescopic cylinder is shown here. It is a two position.

Here it is a inlet port and here you will see the stop ring bearing ring with a groove oil. This is a bearing ring, wiper rings and these are the seals. The front bearing assembly on each section includes seals and a wiper rings. Stop ring limit the moment of each section, thus preventing the separation.

When the cylinder extends all the sections move together until the outer section is prevented from further extension by the stop ring. The remaining section continue out stroking until the second outermost section reaches the limit of its stroke. This process continues until all the sections are extending, the innermost one being the last of all the tubes.

For a given input flow rate, the speed of operation increases in steps as each successive section reaches the end of its stroke. Similarly, for a specific pressure, the load lifting capacity decreases for each successive section.

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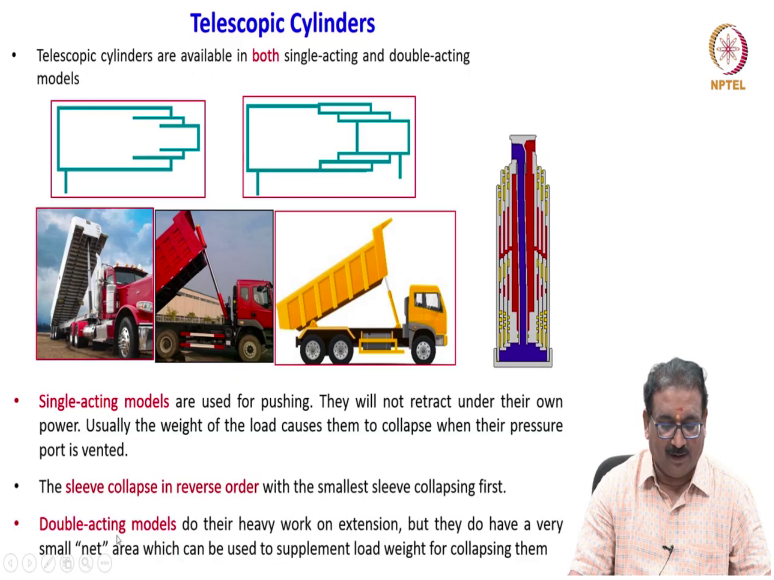

Telescopic cylinders are available in both single acting as well as a double acting models. You will see here the nested tubes one inside the other. Here it is the only one line, it is the single acting telescopic cylinder. Meaning, only extension retraction by the self weight or a vertical positioning of the telescopic cylinder.

You will see in the double acting see there are the two lines are there. Meaning, extension of the sleeve through the fluid pressure, similarly, the retraction of the sleeve through the fluid pressure. It is a double acting type. The application you will see the various applications in constructions, agricultural, many places.

Single acting models are used for pushing. They will not retract under their own power. Usually, the weight of the load causes them to collapse when their pressure port is vented. Only these are used to push the loads. Then retraction is when you will cut off the inlet pressure automatically due to the self weight they will come one inside the other.

The see the sleeve collapse in reverse order with the smallest sleeve collapsing first. Next in the case of the double acting models do their heavy work on extension, but they do not have a very small net area which can be used to supplement the load weight for collapsing them.

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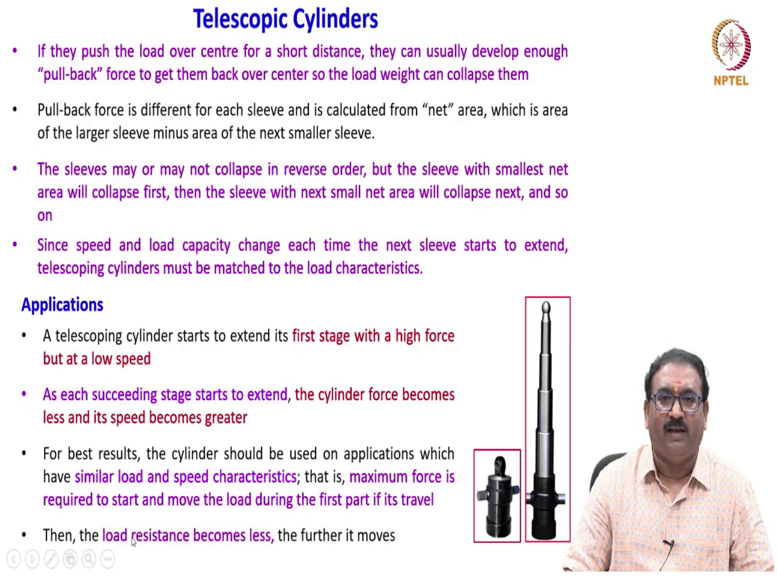

If they push the load over centre for a shorter distance they can usually develop enough push back force to get them back over center, so, the load weight can collapse them. Pull back force is different for each sleeve and is calculated from net area, which is the area of the larger sleeve minus area of the next smaller sleeve.

The sleeves may or may not collapse in reverse order, but the sleeves with smallest net area will collapse first, then the sleeve with next smaller net area will collapse next and so on it will continue. Since the speed and load capacity change each time the next sleeve starts to expand, telescopic cylinders must be matched to the load characteristics.

Now, let us I will give you some application areas where these are used. A telescopic cylinders what I have shown you here vertically mounted here. A telescopic cylinder starts to extend its first stage with a high force, but at a slow speed. As each succeeding stage starts to extend the cylinder force becomes less and its speed becomes greater.

Please note friend this. For best results the cylinder should be used on application which have a similar load and speed characteristics. That is maximum force is required to start and move the load during the first part of its travel. Then, the load resistant become less the further it moves.

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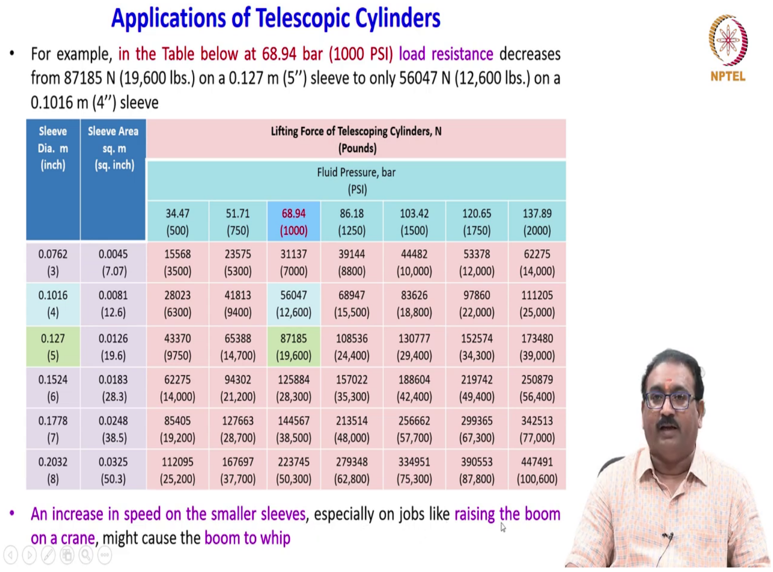

Sleeve Dia. m (inch)	Sleeve Area sq. m (sq. inch)	Lifting Force of Telescoping Cylinders, N (Pounds) — Fluid Pressure, bar (PSI)						
		34.47 (500)	51.71 (750)	68.94 (1000)	86.18 (1250)	103.42 (1500)	120.65 (1750)	137.89 (2000)
0.0762 (3)	0.0045 (7.07)	15568 (3500)	23575 (5300)	31137 (7000)	39144 (8800)	44482 (10,000)	53378 (12,000)	62275 (14,000)
0.1016 (4)	0.0081 (12.6)	28023 (6300)	41813 (9400)	56047 (12,600)	68947 (15,500)	83626 (18,800)	97860 (22,000)	111205 (25,000)
0.127 (5)	0.0126 (19.6)	43370 (9750)	65388 (14,700)	87185 (19,600)	108536 (24,400)	130777 (29,400)	152574 (34,300)	173480 (39,000)
0.1524 (6)	0.0183 (28.3)	62275 (14,000)	94302 (21,200)	125884 (28,300)	157022 (35,300)	188604 (42,400)	219742 (49,400)	250879 (56,400)
0.1778 (7)	0.0248 (38.5)	85405 (19,200)	127663 (28,700)	144567 (38,500)	213514 (48,000)	256662 (57,700)	299365 (67,300)	342513 (77,000)
0.2032 (8)	0.0325 (50.3)	112095 (25,200)	167697 (37,700)	223745 (50,300)	279348 (62,800)	334951 (75,300)	390553 (87,800)	447491 (100,600)

For example, in the table below this table will show you the lifting force on a telescopic cylinder for the different sleeve diameter what I am given here at a sleeve area for the different fluid pressures. Here we will see from this table we will see friends in the table below. For example, for the telescopic cylinder working with a pressure 68.94 bar load resistance decreases from 87,185 Newton on a 0.127 meter sleeve to only 56,047 Newton on a 0.1016 meter sleeve.

Then if the third sleeve is there again it will reduce to 31,134 for the per selected pressure. Meaning as we will move as it will extend fifth, fourth, third, first, the lifting load goes on decreasing, see here. This is one of the important observation in case of the telescopic cylinders. An increase in speed on the smaller sleeve, especially on jobs like raising the boom on a crane, might cause the boom to whip.

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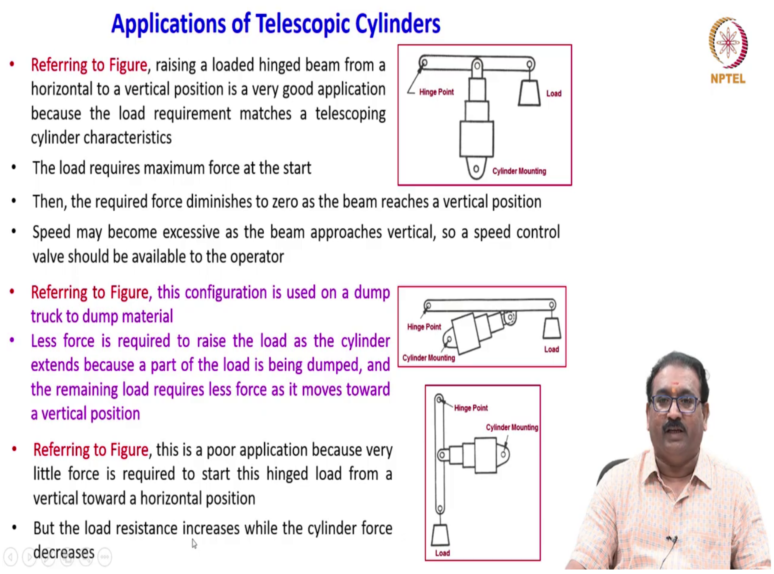

Now, we will see one more application here what I have shown here in this sketch. Referring to figure, raising a loaded hinged beam from a horizontal to a vertical position is a very good application because the load requirement matches a telescopic cylinder characteristics. You will see hinged point.

When the one tube other tube extends the load will be lifting up. The load requires maximum force at the start that is why it is a very good application. Then the required force diminishes to zero as the beam reaches the vertical position. Speed may becomes excessive as the beam approaches a vertical. So, a speed control valve should be available to the operator.

Another application you will see here. It is a hinged point now here. The load is here. It is the cylinder mounting here in the inclined position. This configuration is used on a dump truck to dump material. Less force is required to raise the load as the cylinder extends because a part of the load is being dumped and the remaining load requires a less force as it moves towards the vertical position.

Now, we will see one more area, where it is a poor application of the telescopic cylinder. Here it is a vertical load and hinged point here. When it will extend what happen you will see. Referring to figure, this is a poor application as I have told you because a very little force is required to start this hinged load from a vertical towards a horizontal position.

That is why such cases you should not use the telescopic cylinders. It is a poor application. But, the load resistance increases while the cylinder force decreases.