Fundamentals of Industrial Oil Hydraulics and Pneumatics
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Lecture no 23
Module no 6
Basic Concept of Hydrostatic Transmission (HST) System

Welcome to the module 6, it is hydrostatic transmission system, this is the 1st lecture which is lecture number 23, Basic concept of hydrostatic transmission system.

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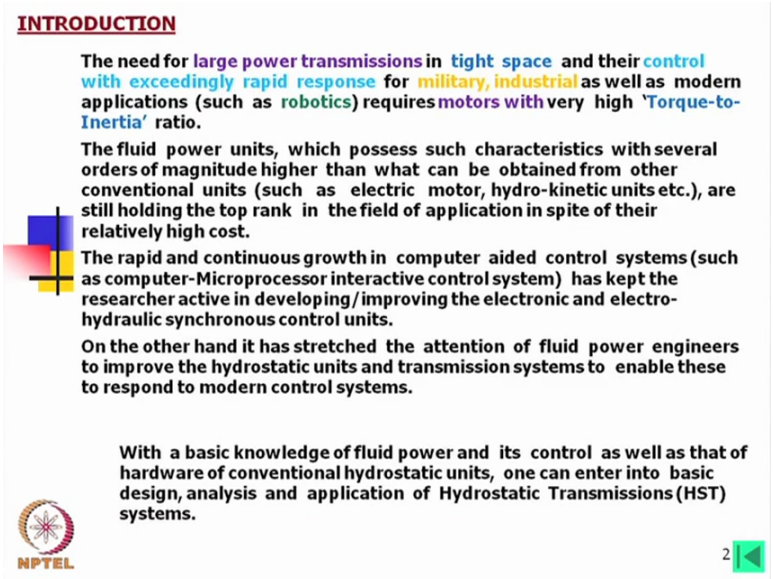

Now here I have described that what we need in the hydrostatic transmission. The need for large power transmission in tight space and their control with exceedingly rapid response for a military, industrial and as well as modern applications such as robotics requires motors with very high torque to inertia ratio. Now respect to the 1st paragraph what actually mean that it is always preferable if the output torque is very high whereas, the total inertia of the machine so to say the weight of the machine is very less.

The fluid power units, which possess such characteristics with several orders of magnitude higher than what can be obtained from other conventional units such as electric motor, hydro kinetic units, et cetera are still holding the top-rank in the field of application in spite of their relatively high cost. If you look into this, I have described earlier in the introduction here I would like to say if you consider a ceiling fan, you will find that about this motor that is rotating the

feeling fan, diameter is 150 millimetre and width is around 50 millimetre but if you look into the power, power is only about 60 or 80 watt.

That size of hydraulic motor can give about 10 kilowatt very high torque, slow speed, so this is definitely beneficial while we are using for general-purpose where we normally need high torque at low speed. However, if we look into the source then for electric motor power is being generated at a distance may be several thousand kilometres away and that is being conducted by over electric wire high tension lines and then there is the transformer that is not at the same complex, maybe outside and you are getting the modified or you say moderate current to use and then you are rotating the fan.

Whereas in case of feed power although we can have centralised power generation, but normally it is equipped with the machine. So if we consider that part, probably then the weight is not less, but always it is the end use, if you think in terms of an use, the water can be made very small and that can be directly mounted where we are utilising this torque. Also the other most beneficial part is that the fluid which is converting the power, that can be carried through a flexible pipeline so therefore this is another advantage that means from the generation of the fluid power to the application point we have flexibility and we can put the motor and the generation source in any direction.

Whereas, if we think of say we are trying to we are considering a drive for the industrial truck or maybe say any automobile equipment. If you go for full mechanical system, in that case what we have to do, we have to put an engine then a gearbox and then a transmission line and they are physically connected with the rigid bodies and they have particular directions, there is not much flexibility in placing them within this the whole machine. In case of electrical of course you can put the generator and the motor in any direction, but with the motor then again you have to connect the transmission line may be through a gearbox, so that part is you cannot put any direction so there should have rigid mechanical connection and the size is also very big.

In comparison to that if you go for hydrostatic transmission, you can put the engine in any direction, maybe pumps and et cetera are connected to that, oil tank you can put somewhere else and your motor you can directly fit in to the wheel hub of the wheel or maybe roller in case of the earthmoving equipment. Now, the rapid and continuous growth in computer aided control

systems such as computer microprocessor interactive control system has kept the researchers active in developing and improving electronic and electric electrohydraulic-synchronous control units.

Now here this is this I would like to mention, the fluid power nowadays it has improved a lot because of introducing the control, which is microprocessor, electronic control within that. That means earlier to this lecture while we are discuss discussing the control of the swash plate, in that case earlier it was may be hydraulic control only. Now along with this hydraulic control we will find that electronic control gives further or better controllability to the system. So with that when we think of the such control system using computer and microprocessor, then sometimes it requires that we need to improve the fluid power unit also to match with this control system to make it compatible with the current system.

So this means that while we are improving the control system as well as we have to improve this hydraulic systems also. Anyway, for that you will find that there is continuous development of this fluid power equipment also, hydrostatic transmission also. Or in other words I would say that hydrostatic transmissions you will find that using the same equipment, using the variety in control we can have, we can improve the performance. On the other hand, it is it has faced the tension of the fluid power engineers to improve the hydrostatic already I have discussed.

With a basic knowledge of fluid power and its control as well as that of hardware of conventional hydrostatic units, one can enter into basic design, analysis and application of hydrostatic transmission system. Here I would like to mention, we normally use HST actually HST means only hydrostatic transmission. Now we should use the word when we are thinking of the system, so therefore we should say HST system that means the total circuit. Now if we say HST unit then it means, the pumps, motors, actuators, et cetera, HST units and HST system. So when we mean HST system then using the pumps and motors, valves, et cetera there is a total system okay.

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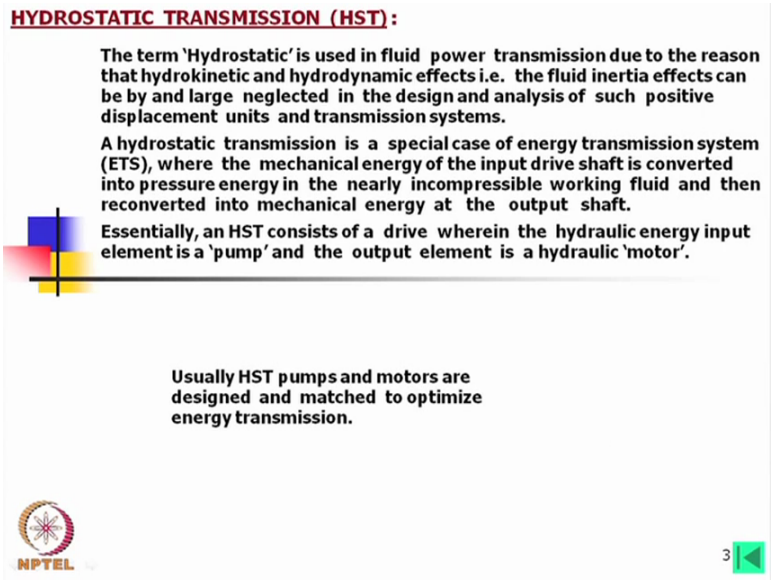

This is already described, again I repeat, the hydrostatic is used in fluid power transmission due to this reason that hydro kinetic and hydrodynamic effects that is the fluid inertia effects can be by and large neglected in the design and analysis of such positive displacement units or transmission systems, so that means HST units or HST systems. Hydrostatic transmission is special case is a special case of energy transmission system ETS where the mechanical energy of the input drive shaft is converted into pressure energy in the nearly incompressible working fluid and then reconverted into mechanical energy at the output shaft okay.

Look at this definition, we may be think of that incompressible fluid means we are only thinking of the hydraulic oil or similar fluid which are considered as incompressible. But no, here it means that whatever may be the fluid, even incompressible fluid, to raise the pressure we compress it, then we utilize it for converting the energy. This this this means that this includes also the gas pneumatics okay. Essentially, an HST consists of hydrostatic transmission consists of a drive where in the hydraulic energy input element is a pump and the output element is a hydraulic motor.

Usually HST pumps and motors are designed and matched to optimise energy transmission. Actually, if you think of the individual pumps and motors then those are designed maybe you can in the market you will find different size of pumps and different size of motors. But you will find

a particular set of pumps if you use with particular set of motors then you will have the efficient or optimise energy transmission.

Now, hydrostatic transmission when we will come into little detail you will find, in most of the cases which are specially designed for hydrostatic transmission, this means that see if you think of the earthmoving equipment, if you think of the construction machines, in many cases you will find that there is a pump, there is a motor, there is a valve, everything are used together to for a continuous sum for a typical operation.

In that case, in many cases both the pumps and motors are designed as a match part. In some cases you will find there integral, the pump, motor and the valve manifold where you will find that inside there is a pressure valve everything and they are put together. So so this means that usually we have to look into the pump motor design when we are thinking of optimisation or optimum energy transmission.

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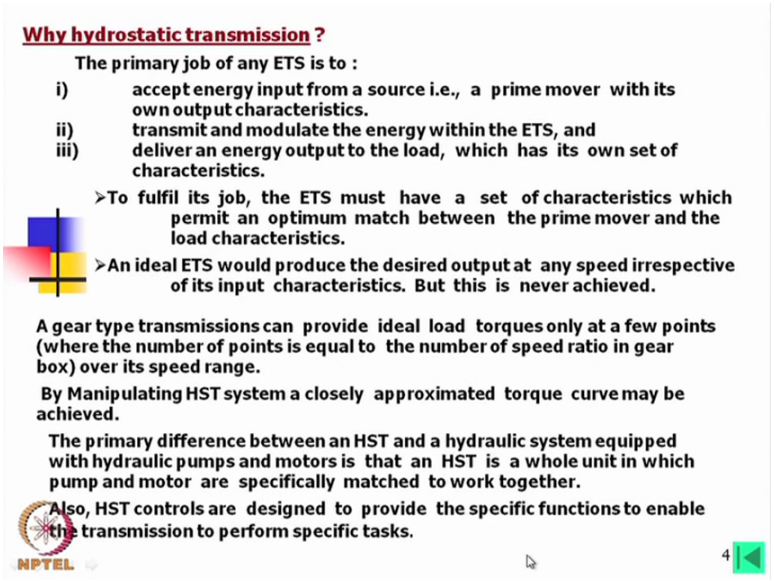

Primary job of an energy transmission system is to; except energy input from a source that is a prime mover with its own output characteristics, look at this. We are using a pump, we are using a motor for the hydrostatic transmission system, but when we are thinking of driving this pump that is having its own characteristics. So and our output will have it needs its own characteristics, so 1st of all from the prime mover to the output we have to match that characteristics. Now

transmit and modulate the energy within the ETS and deliver an energy output to the load, which has its own set of characteristics okay.

To fulfil its job, the energy transmission system must have a set of characteristics which permit an optimum match between the prime mover and the load characteristics. An ideal energy transmission system would produce the desired output at any speed irrespective of its input characteristics, but this is never achieved. A gear type transmission can provide ideal load torque only at a few points where the number of points is equal to the number of speed ratio in gearbox over its speed range.

For example, you must be using the car think of the car transmission, in that case you often say this is a four-speed gearbox so one when there is a high ratio highest ratio that is for the starting. So it starting there will be high inertia because the components are accelerating and it is overcoming the static friction, so in that case you need high torque. So what is done from the engine to the wheel, we provide the maximum transmission ratio of the gears. Now gradually when it starts moving, gradually the torque is reducing so the situation is improving that the torque is reduced so you can use the now energy of the unit to transmit a high-speed at low torque because the torque requirement has reduced.

So what we do, feeling that if it is a manual car we change the gear shift the gear and the transmission ratio is reduced. In that case gradually we reach at a final stage where almost you can say that engine speed is equal to the differential input speed, then within differential there may have a slight 1 stage reduction. Usually you will find that differential there is one stage reduction and then differential is there. Now by gearbox what we are doing, we are using this engine power at 4 different speeds and each different speed is having its own characteristics and we are putting the actual torque requirement within these 4 different regions, okay.

In case of hydrostatic transmissions what can be done, this can be continuously variable from starting to end. However, there is in that case you may ask that why we do not use the hydrostatic transmission for car? The answer is very simple, in case of the car the this torque range is very high that means when a car is moving at a constant high-speed except some inertia even if you consider that except some resistance, maybe a little road resistance and the air resistance, there is

no real resistance is there so we do not need any power, we can move. But in case of if you would like to have such a range from the fluid power equipment that is not possible.

So with a fluid power hydrostatic transmission system, to have such a range we have to again we have to use a box which is not benefited. So hydrostatic transmission is mostly suitable that if this range of this speed is not very high, say let us consider the road roller or the other earthmoving equipment where for the basic purpose for which such machines are designed, you will find the speed range is very small. If you if you moving with a road roller from one place to other place, you will find that it is not benefited, it is very slowly moving but when it is moving its job, it is required okay.

By manipulatiing HST system, a closely approximated torque curve may be achieved but that definitely not in the range of what is required for a car. The primary difference between an HST and the hydraulic system equipped with hydraulic pumps and motors is that an HST is a whole unit in which pump and motor are specially matched to work together, this I have mentioned while I was discussing. Normally, we call the HST system is a the system of the fluid power where the pump and motor are put together and they are matched to achieve a specific purpose. Also, HST controls are designed to provide the specific functions to enable the transmission to perform specific tasks.

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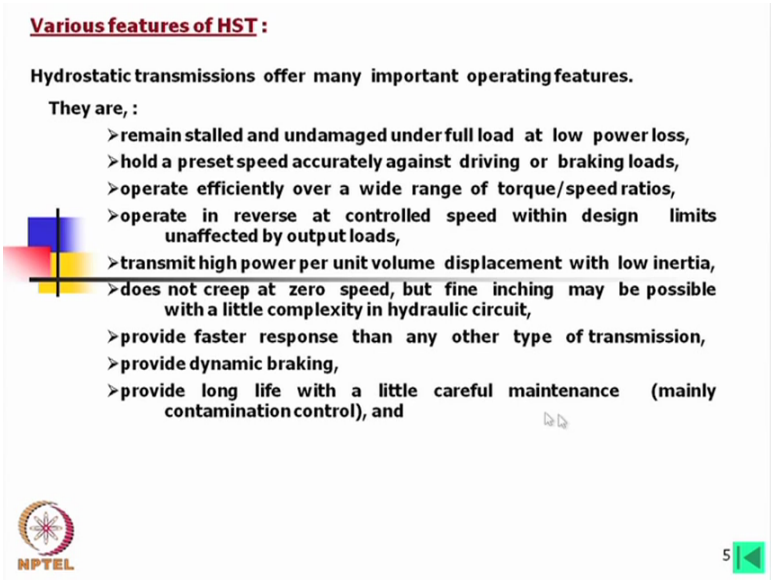

Hydrostatic transmission offer many important operating features, which are; remains stalled and undamaged under full load at low power loss. This means that we can achieve stalled condition sometimes which is required, but the oil is only circulating within the system so power loss will be less. This means that suppose say we put actually some some actuator is moving or something is moving and it is transmitting a torque and it is it is doing a job, but what we want that maintaining the pressure it is just holding there it is not moving. In that case definitely we have to raise this pressure and the fluid has to pass through this.

So what can be done in case of variable piston swash plate type pump, what we can do, we can make the swash plate with 0 position almost 0 position. This means while it is only supplying maybe the leakage oil but with the full pressure, now how much the energy being required for that the because the flow is very small, so flow into pressure gives the power so power is less, so that is possible with hydrostatic transmission system. In case of other, it could not be possible say, engine and gearbox system this may not be possible. Hold a pressure speed accurately against the driving or breaking loads, operate efficiently over a wide range of torque and speed ratio.

Operate in reverse at controlled speed within design limits unaffected by output loads. Transmit high-power per unit volume displacement with low inertia. Does not creep at 0 speed but fine inching may be possible with a little complexity in hydraulic circuit. Now here I would like to say, let us consider you have you are working with a (())(24:01) or similar industrial track, now this transmission this moving transmission is maybe with gearbox, I mean change speed gearbox, engine, et cetera like car but here the torque range may be different however, this lifting, etc is done by hydraulic.

Now in case of warehouse operation normally what is required, you have to list the load then you have to come back and also for the positioning the load you have to move very slowly. With engine gearbox the conventional drives it is very difficult whereas, in case of hydrostatic transmission this engine speed is possible, only a small displacement it will just the this track very slowly, so that is another important aspect of using hydrostatic transmission system. Provide faster response than any other type of transmission, the response through fluid high-pressure is very quicker than any other system.

Provide dynamic braking, say if you just close the oil path, you will find whole thing will be stalled, in case of high pressure rise of course it will go to the relief valve, but normal case you will find once you just move the valve, close the flow path immediately it will have an braking effect. Provide long life with a little careful maintenance, mainly the contamination control, here I would like to mention although it is written here but in most of the cases the failure of fuel power system due to the contamination. So although you may not need very much maintenance but you need to routine maintenance, we should do that otherwise this will fail, but with little maintenance definitely fluid power is better, and lastly provide flexible transmission lines that I have explained.

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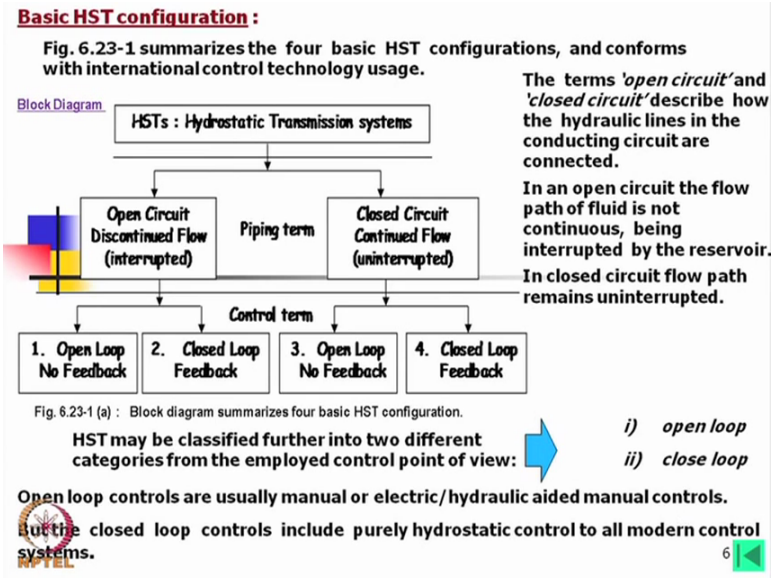

Now, if we consider the hydrostatic transmission system, again I will repeat hydrostatic transmission system means we will consider the pump, motor together including the Valve that means we should not consider the prime mover which is being used as a input, we shall consider the ultimately what work is it is doing, taking the output from the motor. But if we consider the motor output shaft or motor actuator to the input shaft of the pump, the whole unit we will consider as a hydrostatic transmission system. Now using that system as I say HST, now this can be open circuit discontinued flow that means it is interrupted flow can be interrupted.

First of all another thing I would elect to mention, in normally hydrostatic machine what we call these are all direct current machines that means for all the flow, output from the pump those are

mixed and then this is forwarded to the motor side, in the motor again this flow is divided into all the Pistons, so flow mixed and then again it is being utilised for the motor so we have to call it DC direct current flow. Now in this direct current if it is called open circuit that means the flow is going to the motor and then it is going back to the tank, it is not coming directly to the input side of the pump, so you should call this is the interrupted fluid.

Now it can be closed-circuit also, in case of closed-circuit what it is? The output of the motor flow is the input of the pump, directly connected. Pump output is the input of the motor, motor output is the input of the pump so simply from this pump and motor hydrostatic unit they again look alike due to the configuration, you will simply connect input to output, output to input it should work theoretically. So this is called piping term, in the piping term we have open circuit and closed-circuit, in case of closed-circuit it is continuous flow uninterrupted, but actually it is not possible because there will be leakage, we will see this how this circuit can be made.

Now again from the controlled term, each open circuit and closed-circuit has open loop that means there is no feedback and there is closed loop which is having feedback similarly, for the closed-circuit also. So basically hydrostatic transmission considering the piping term and the control term we can have 4 basic transmissions okay. Now the term open circuit and closed-circuit describes how the hydraulic line in the conducting circuit are connected, which I have explained. In an open circuit the flow path of fluid is not continuous, being interrupted by the reservoir, it is going back to the reservoir and from the reservoir again it is being pumped in by the pump.

In closed-circuit, flow path remains uninterrupted. HST may be classified further into 2 different categories from the employed control point of view which I have explained that is the open loop and closed loop, it is sometimes it is termed as closed loop or close. Open loop controls are usually manual or electric/hydraulic aided manual controls, either it may be manual or electric/hydraulic aided manual controls that means you are basically on-off switching is being operated. But the closed loop controls include purely hydrostatic control to all modern control systems.

Now here I would like to mention although it is said that it is hydrostatic control, but the hydrostatic unit itself might be again electronically controlled. Say for example, we can make

such a closed loop control using a proportional Valve where the proportional Valve is being controlled by electronic system, do not confuse that but usually the whole unit we would say the hydrostatic control is there okay.

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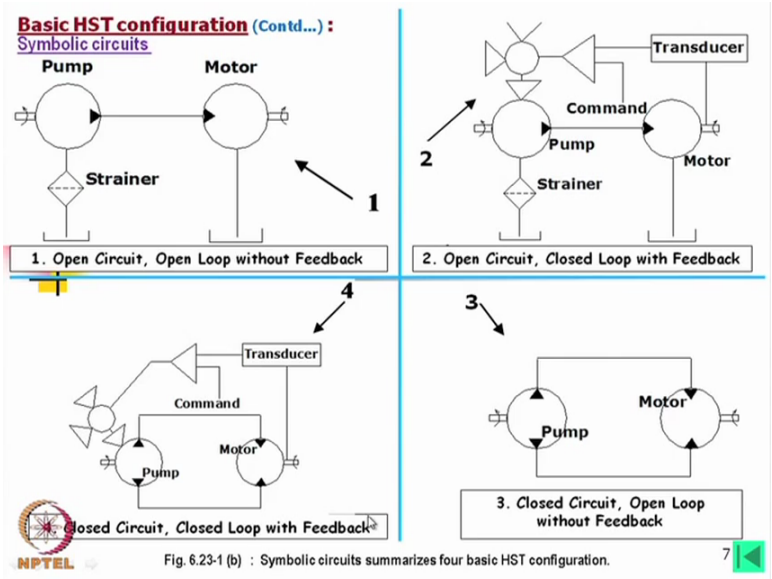

Now, if we try to understand through this symbolic representation, we see that this is a unidirectional pump and this is a unidirectional motor, they are simply connected like this and oil is from the reservoir and oil is going back to the reservoir. So we should consider this definitely open circuit and also it is open loop without feedback, no control is there so this is open circuit and open loop.

Now next one is that this is open circuit but there is a transducer, you see this any control feedback control system or even if it is not feedback, what we need that there should have a transducer, say this is a constant speed or maybe constant torque whatever it might be. So we need a transducer and then there should have the control system and through which the pump is being controlled either to either for the concentration or for the constant speed.

Now 3rd one is that the closed-circuit, you can see this pump input to motor say motor output to pump input and pump output to motor input like this. And you see here what suppose this is the direction of the pump flow out, so it is going this way and it is coming back this way so for which may be this is being rotated anticlockwise and this also the output is anticlockwise like that. But it is possible that here either rotating in the opposite direction or keeping the direction

same, we can change the direction of the flow and thereby we can have we can rotate in the opposite direction also.

Usually in hydrostatic transmission where it is a closed-circuit, in that case the direction of the pump rotation remains same, whereas by changing the swash plate in the opposite directions we can change the direction of the input output of the pump, thereby we can rotate the motor in both directions. Consider a fort lifter, consider any industrial truck, consider any earthmoving equipment which is driven by the hydrostatic motors, in that case transmissions are like that, engine is giving the output in single direction.

Pump is fitted to that but bearing the swash plate from one side to other side we can change the direction of the flow of the pump thereby we can rotate the motor in the in both direction. And then lastly, this closed-circuit will have also the closed loop feedback. This is say this usually this type of transmissions are used in many machines where the control is manual, a driver is controlling but in many cases you will find this is having closed loop control also. Say if we have some say remote control or maybe automatic control or some moving equipment, nowadays you can think of the guided vehicles, automatically guided vehicles, in that case also usually will find closed loop. There are many other cases also where it will be closed loop.

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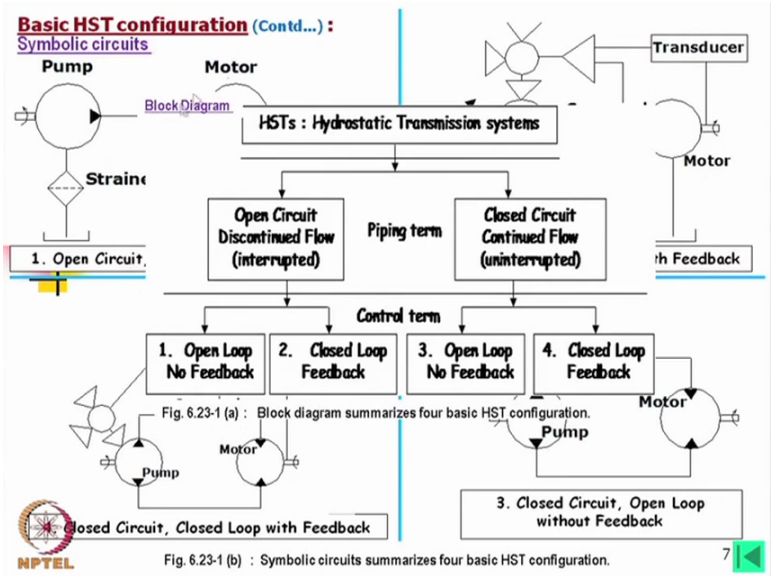

So here again you can say we can look into this, so these are the 4 possible transmission systems, hydrostatic transmission system, now we shall consider up at closed-circuit.

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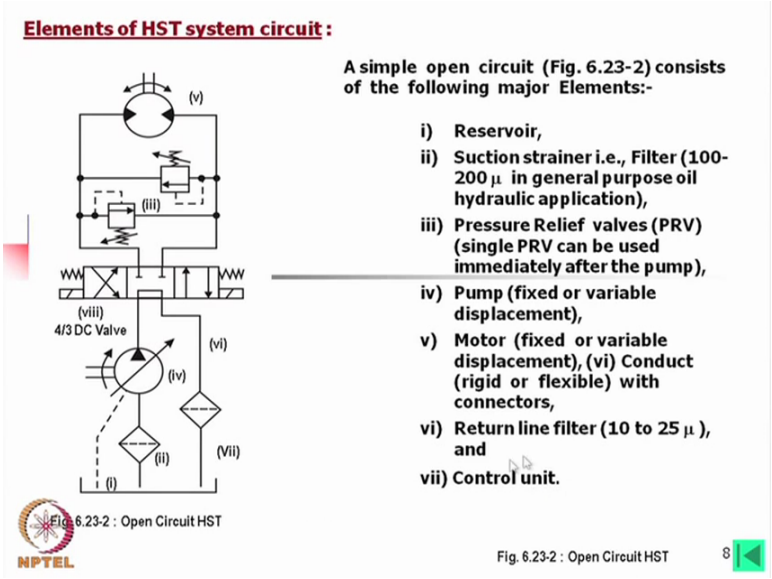

Now what we find here that this is the pump, this is the suction filter, first of all let us consider the reservoir is there, next this is the suction strainer, this is usually 100 to 200 micron in general-purpose oil hydraulic application okay, so this is the suction strainer. And then we are having the pressure relief Valves here, we are having the pressure really Valves. This pump okay we have used the pressure relief Valve here instead of using here. Now the pump fixed or variable displacement, this pump it might be fixed or variable displacement, in this case what is shown that it is variable displacement okay, it might be also fixed displacement.

Next we have this motor, fixed or variable displacement and there is this is sorry this will be conduit, this is not conduct this will be conduit rigid or flexible with connectors, there we will need connectors there. Then we will have return line filter, this is the return line filter okay. Now return line filter is usually 10 to 25 micron okay, why it is like that? If we put, actually we need the oil of such filtration 10 to 25 micron even if it is for general-purpose, but if we put such an element in the suction line then pump will have it will have additional load. And sometimes as these are very poor suction capacity, in that case sometimes the suction will fail that is why always we put these 10 to 25 micron filters in this in the return line.

Contamination is coming through actually in this case there is little chance, but if we drive an actuator such an cylinder piston, in that case usually dust comes through the piston rodent so we need to have a good quality of filtration there. Now apart from that there will be control unit,

then I am sorry there it is perhaps it is a mistake, the earlier one if you go back to the earlier one, this is not written, that we need a directional control Valve, this is as I told this is open circuit so we must need a direction control Valve to operate this okay. So the reservoir, then suction, then pressure relief Valve, pump, motor, conduit, return line, control unit, this control unit actually includes this direction control Valve also.

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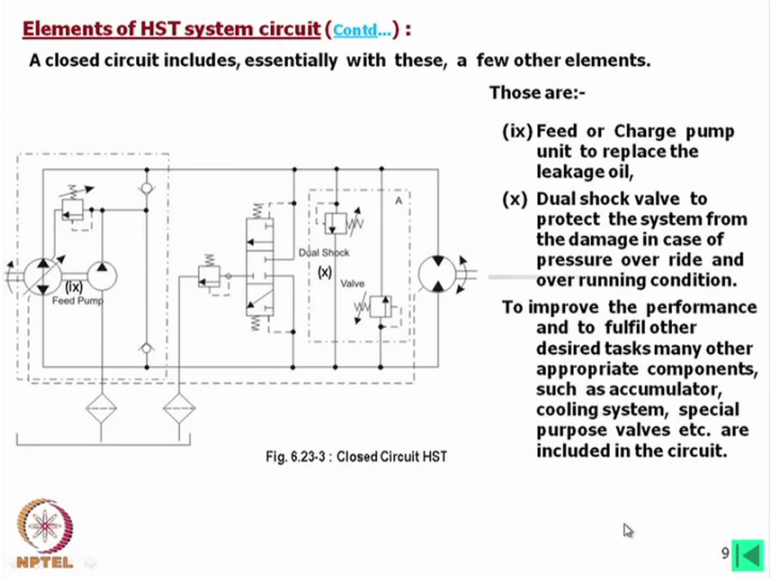

Now we shall discuss about a closed-circuit hydrostatic transmission unit. In closed-circuit hydrostatic transmission unit, the component what we need for open circuit those are there. Apart from that we need feed or charge pump, actually closed-circuit means as I have explained pump output to motor input and water output to pump input. So ideally we do not need in ideal case we do not need anything, simply if you rotate the prime mover, it will rotate the pump and this pump will rotate the motor, but what happened there is a leakage so you will find that initially if it is completely filled with fluid, the motor is rotating but after some time you will find the motor is not rotating, so what is that, we need a feed pump.

This feed pump, look at this, this is very quiet interesting. This feed pump it is having a relief Valve and then it is going through 2 non-return Valves. Suppose this oil is from the pump is flowing in this direction okay, then it is being rotated. So definitely this is very high-pressure, as it is high-pressure so the ball is closed, now this pump is having very low pressure it is only

filling the oil so what it is, it is trying to move in this direction, now this is the return line here the pressure is very low so oil is going to this okay.

Now whatever the leakage whatever the loss due to the leakage, now this pump is having very low pressure, it is only filling the oil. So what it is do, it is trying to move in this direction, now this is the return line, here the pressure is very low so oil is going through this okay. Now whatever leakage, whatever the loss due to the leakage that will be completely filled by this pump. Now if it is try to usually this is fixed displacement but very low volume, now if it is trying to pump additional oil to the circuit, it cannot take because these are all say non-flexible conduits we should consider, although it is flexible but it is not elastic.

In that case, the soil is going to this pressure relief Valve okay and it is going back to the tank for maybe again to this pump, here the connection is so it is going through this pump. Now next so adding this feed pump it should work okay, but look at this, this pump is having no relief Valve because if I provide a relief valve there then (())(44:32) oil will pass through this so closed-circuit concept will not work but we need to have some pressure relief Valve otherwise if the load is very high, if it exceeds the capacity then in that case the whole system will fail, it will burst so therefore these pressure relief valves are there.

Now how it is working, it is it is called Dual shock Valve. Let us consider the oil is going like this, so this this is the high-pressure line. Now one pressure relief Valve is connected like this, now if the pressure is high that means it is higher than the for which it is set, in that case it will move like this and it will go back to the pump so pump will rotate and this oil will circulate. When the oil is flowing in this direction then this pressure relief Valve will work, we cannot put a single pressure relief Valve so that is why it is called dual shock Valve. Usually either you can put 2 separate pressure relief Valve or this whole system is integral system, a single manifold is used for that.

Now here again we have another Valve we have used for the purpose of filtration, so we can by moving this we can take the oil out. When we are closing, if you close this one then oil is first filled and then operation starts, if you open it oil will come out to the tank for the cleaning purpose. Now this you may ignore to imagine a hydrostatic closed-circuit hydrostatic transmission system. To improve the performance and to fulfil other desired task, many other

appropriate components such as accumulator, cooling system, special-purpose Valve, et cetera are included in the circuit.

Now I would like to mention that suppose you need less fluctuation, you can put an accumulator this side as well as this side also and accumulator only with the high-pressure so there should have bypass circuit also that can be provided here . You need filter oil for the operation say for example, in case of servo controlled valve, at the utilisation side you need to you need that oil to filter 5 micron or even less, in that case a high-pressure filter is used in all lines. So all such components can be added to make the circuit more efficient, more workable condition.

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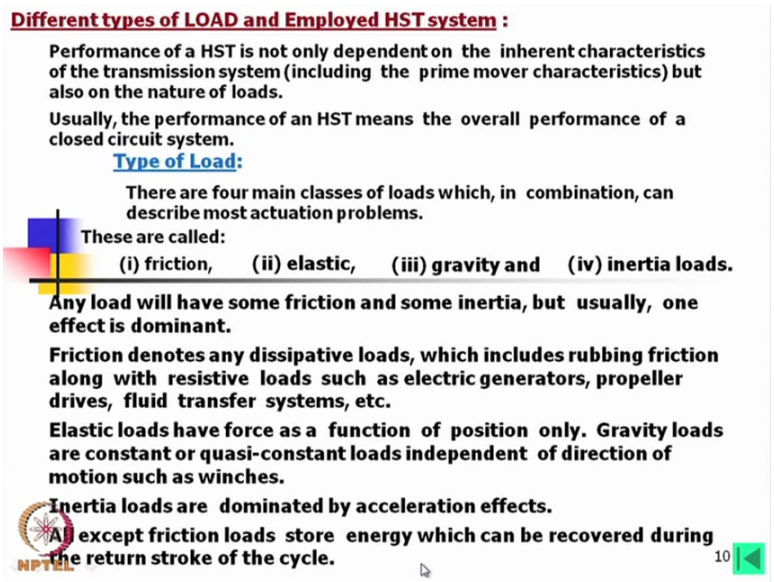

Performance of a HST is not only dependent on the inherent characteristics of the transmission system including the prime mover characteristics, but also on the nature of loads. Definitely, depending on the nature of load there will be variation in HST performance. Usually the performance of an HST means the overall performance of a closed-circuit system. When we mean the performance of hydrostatic transmission system we consider it is a closed-circuit system. Now what are the types of loads that we should know, there are 4 main classes of loads which in combination can describe most actuation problems.

These are called one is friction, there will be friction in each and every component motor, linear actuator, everywhere there is friction. Now than the elastic load, that means whenever you are applying the pressure there will be the elastic difference in all the components there so that is

also (())(49:19) the 1st energy goes to expand the elastic bodies, friction is there to move the bodies. Next comes the gravity, gravity loads are there so that we have to consider and then comes inertia load. Now any load will have some fiction and some inertia, but usually 1 effect is dominant normally it is like that.

Friction denotes any dissipative loads, which includes rubbing friction along with resistive loads such as electric generators, propeller drives, fluid transport systems, et cetera. Elastic loads have forced the pension of position only. Gravity loads are constant or Quasi-constant loads independent of direction of motion such as winches. In case of winch what it is, it is moving load it upward direction so (())(50:38) is being winding and so this is the gravity load, we are providing this hydrostatic load to move the such load.

Now inertia loads are dominated by acceleration effect, so this load only active when there is acceleration. Now all say if you consider the elastic Load, if you consider the inertia load, if you consider the gravity load, all are say store energy. Say for example, if you lift a load by wench then you can recover the energy because if you lift the load to fall, you can recover the energy except the friction, friction you cannot recover, we should be careful about reduce the friction and as much as possible. But other load also suppose the load we lift in that is not utilised for recovery of power to use somewhere, but in some cases you can use that power also.

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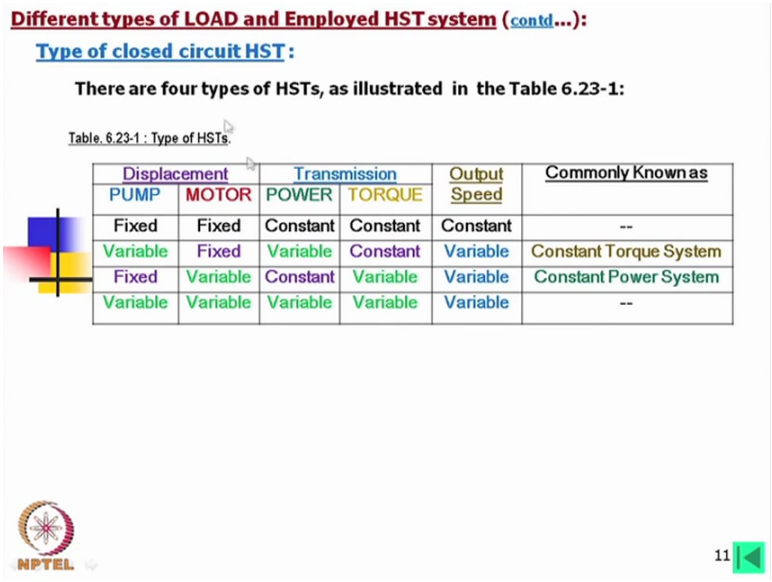

Now, if we think of the closed-circuit then there are 4 types of hydrostatic transmission as illustrated here. It can have both pump and motor fixed and then power constant and torque constant, so this is output speed also constant, all are fixed purpose. Usually you will find that pump is variable drive and then motor is fixed displacement, in that case power is also varying because depending on the motor I mean pressure side we can vary this flow and we can keep this power variable, where as we can keep this torque constant, the system is widely used which is called constant torque system mostly used.

Can have also pump fixed motor variable, whereas power will remain constant but torque varying, so this is in a sense this is better but in normal cases we need to have various range, this does not means we are only one single torque we are setting, it is like that keeping the torque constant you can vary the power so this is energy-saving than this system, concern power system.

Now you can make all variable, is making all variable means it includes all 3 you can keep all fix so it will behave like this if you keep fix and make this, it will be like this and 3rd is that if you keep this fixed and this variable. So this system although it is expensive, but if you make this sys if you design or if you use a system with all variables then you can have all other key features within the system.

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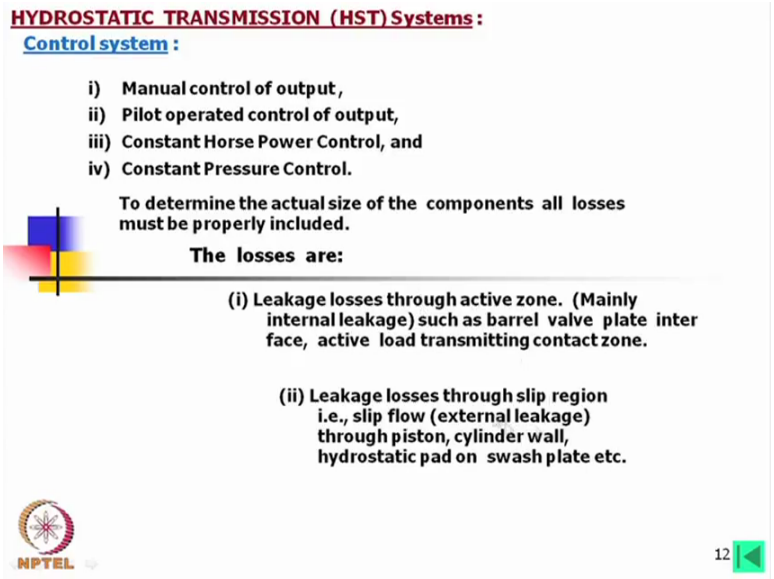

Now control system may be manual, control pilot operated control, constant horsepower control and constant pressure control, anything you can achieve, you can design the system like that. To

determine the actual size of the components all losses must be properly included that means while you are considering the design it is not that suppose if you need the motor say 20 newton meter and maximum speed 100. So if you ideally select pump of that size, you will find exactly matching size, you may find that you are not getting the full performance, you have to consider the pump oversize why because there are many losses so to compensate that losses pump should be of higher size, how much higher size it should be for that you need to calculate all losses together while you are estimating the performance.

The losses are leakage losses to the active zones, mainly internal leakages such as barrel Valve plate interface, active load transmitting contact zone. And leakage loss is through the slip region that means there are external leakages say through the piston, this oil is going out of the barrel and it is going inside the cases so we have to consider such leakages also carefully and this is internal leakage this first one and this is one the external leakage.

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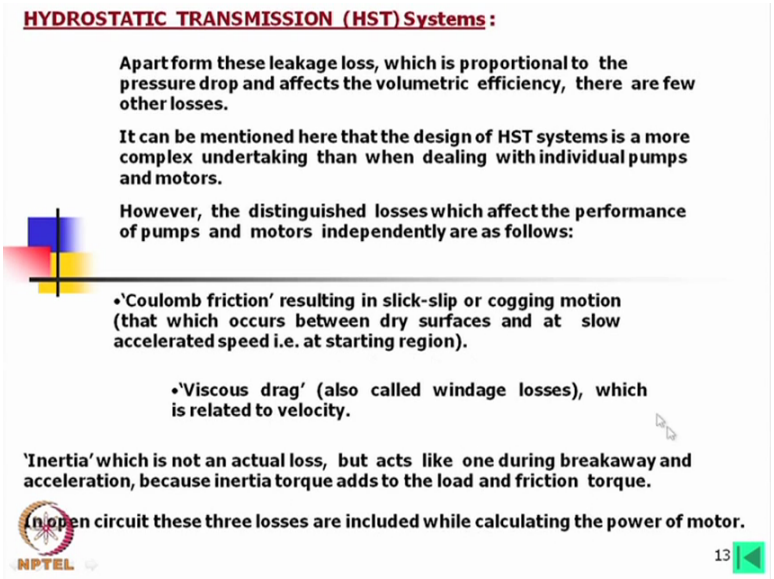

Apart from this leakage loss which is proportional to the pressure drop and affect the volumetric efficiency, there are a few other losses. It can be mentioned here that the design of HST system is a more complex undertaking than when dealing with individual pumps and motors. Actually I would like to say that what is the advantage of the say hydrostatic transmission system which is usually again closed-circuit? The advantages that this has very quick response and return line is not the always with the lowest pressure atmospheric pressure. You may find this pressure

difference they maintain in such a way, the performance we achieve through such an hydrostatic transmission in a far better way than the open circuit.

Now this we should consider the coulomb friction which is stick-slip or cogging motion that is in case of Pistons you will find that the starting particularly there is the friction motion that we will also consider while we are particularly estimating the torque of hydrostatic unit or maybe the total system also we must consider the viscous drag. Inertia which is not an actual loss, but acts like one during breakaway and acceleration, because inertia torque adds to the load and friction torque. You see this initial stage at starting we must have took consider the inertia also. In open circuit, these 3 losses are included while calculating the power of motor. In case of closed-circuit we have to we can compromise which has load.

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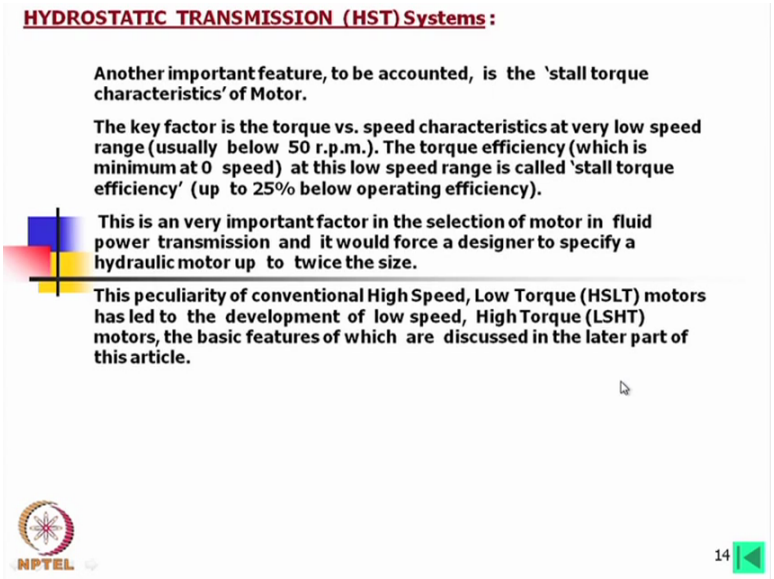

Another important feature to be accounted is the stall torque characteristics of motor. Usually if you would like to stall for example, in many cases we need to stop the machine but holding the torque, so for that characteristics also we should consider because if you would like to hold the load at a particular position your motor may slip so that is to be accounted. This is an very important factor in the selection of motor in fluid power transmission and it would force a designer to specify a hydraulic motor up to twice the size, in many cases you will find due to this reason only you have to increase the size of the motor.

Now here I would like to mention, for that special-purpose voters are also designed. Normal course we use the high-speed low torque motors, but we can have also low speed high torque motors.

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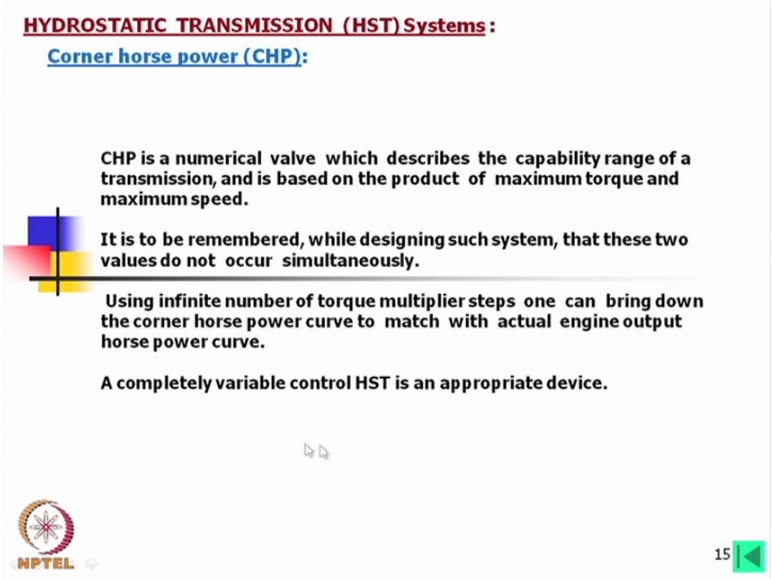

Now another thing is the corner horsepower, what it is called? Corner horsepower means maximum torque and maximum speed, at that condition we have to achieve so every design that means particularly when the motor is at its high speed and high torque, what is the power that has to be considered to select the pump including all other losses. So it is to be remembered, while designing such system that these 2 values do not occur simultaneously. So if that occur simultaneously, it means you have to use power and we get the multiple steps within such hydrostatic transmission system, so a completely variable control HST is an appropriate device.

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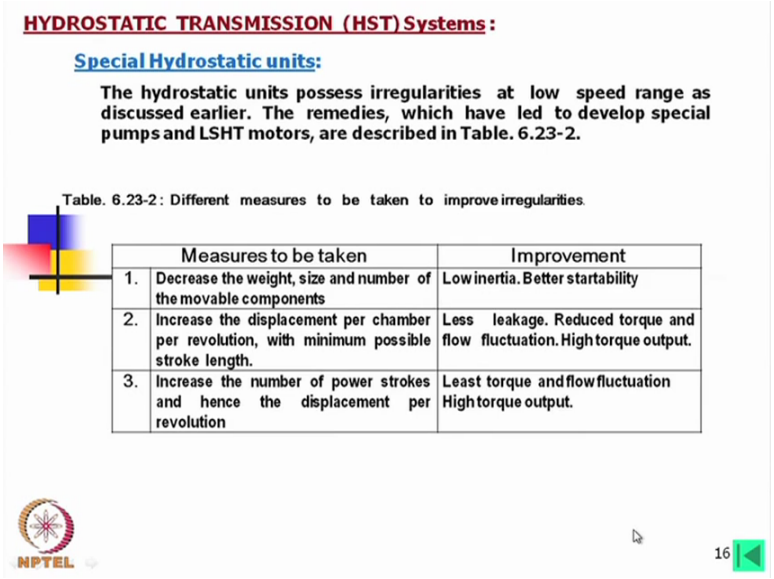

Now we can also go for special hydrostatic transmission unit, which that first of all what we should do? Decrease the weight, size and number of the movable complaints, so low inertia, better start ability. And increase the displacement per chamber per revolution, this is the leakage loss, reduced torque, et cetera. Increase the number of power strokes and hence the displacement per revolution, so least torque and flow fluctuation, high torque output.

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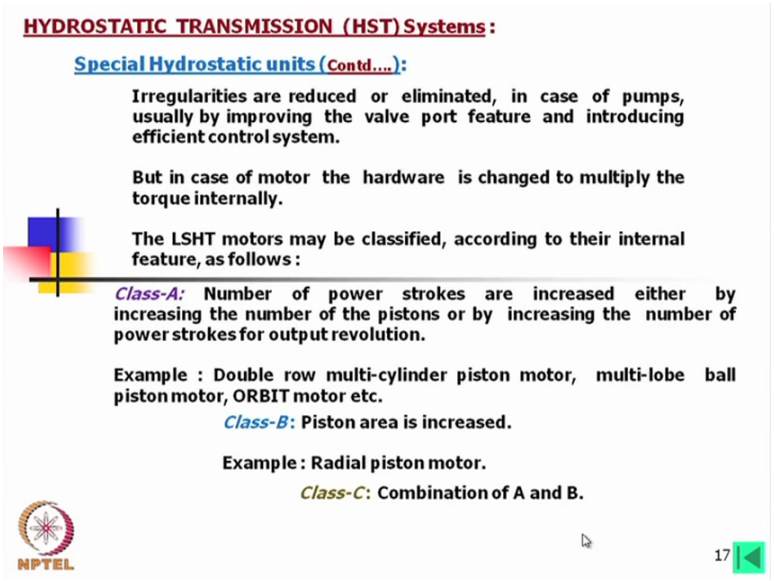

So we can also reduce the irregularities but in case of motor and hardware is changed to multiply the torque internally. The LSHT low speed high torque motors may be classified according to the

internal features as follows. Now we can design the low speed high torque motor, we can increase the number of power strokes and increasing in the number of Pistons or by increasing the number of power strokes for output revolution. This is say examples are double row multiple cylinder piston motor, multi-lobe ball piston motor, orbit motor, et cetera.

Now class B is the piston area is increased, the best example is the Radial piston motor, which we have learned earlier little bit. And 3rd is the combination of A and B, the example is that Multi-lobe radial piston motor, Multi-lobe radial ball piston motor, et cetera. So this is the end of this lecture and I would like to say we have not specified any references here because this is the very general knowledge, it is this notice prepared consulting many, so no special reference for that, okay thank you.