Fundamentals of Industrial Oil Hydraulics and Pneumatics
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Lecture01
What is Hydraulic and Pneumatic Systems?

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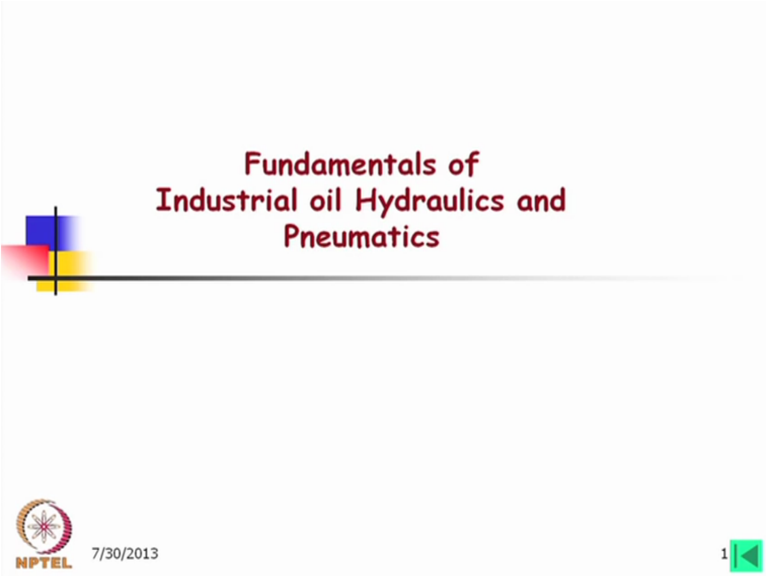

Welcome to this NPTEL course on fundamentals of industrial oil hydraulics and Pneumatics.

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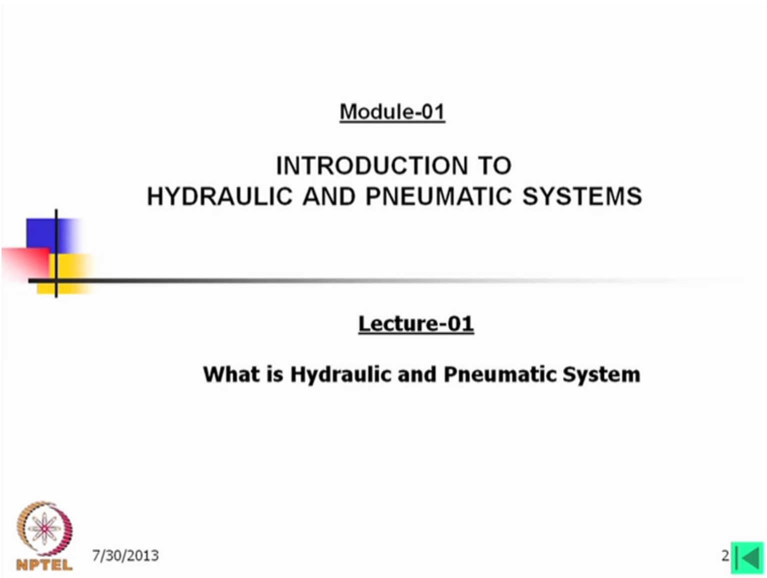

So first module is introduction to hydraulic and Pneumatic Systems and this is lecture 1, where we shall discuss what is hydraulic and Pneumatic System.

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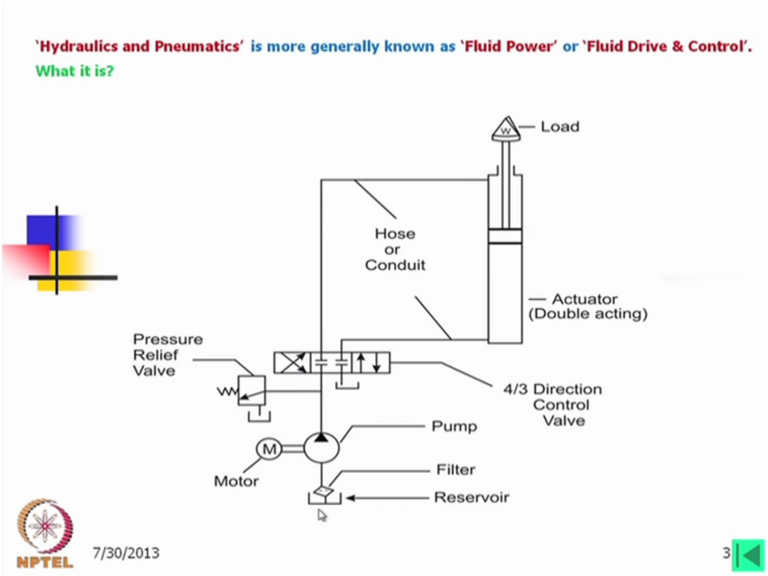

Hydraulics and pneumatics is more generally known as fluid power or fluid drive and control, but let us know what it is. Consider a load which is to be lifted to a height. There are many other mechanical means, but we can think of an actuator which is piston cylinder, we can put it vertically and on the piston end and we can put the load, which can be lifted by means of lifting the piston through fluids.

Now we will think of supplying the oil to the cylinder and we will think of a pump. So we have put a pump. Now can directly connect this pump to the bottom of the actuator and then we can lift the load, but the question is that when the pump will run, how we can take out the oil to lower the load. Therefore, we need some means that we have to the oil out. Now what we can introduce? This is a valve which is named as 4 by 3 direction control valve, I shall describe later what is means by 4 by 3 direction control valve, but looking into this what we find that pump is connected to one port and then there are two ports at the top and another bottom ports which is apparently draining the oil.

Now we can connect this valve to the cylinder by conduit or pipe. Then one end is connected to the bottom other end is connected to the top of the double acting actuator and then if we looked into the left side of the direction control valve then this pump will be connected to bottom there is slight mistake in the arrow then the top side will be connected to the drain and load will be lifted. Similarly if we actuate this valve to right side then this will go to the drain and the oil will be will enter through the bottom, sorry through from the top and load will come down. Now we need a supply of oil to the pump which is called the reservoir sometimes it is called tank also and of course, as we are umping the fluid, we need a filter there. Now this pump will be driven by motor or the prime mover which may be electrical which maybe an IC engine, which may other means of drive.

So this is the basic things and this would work, but there is another an important question that if this load gets truck (())(5:10), then this pump which is pumping the oil will be pressurized and there will be there might have an accident, because tis hose can burst due to the pressure. So if the pressure rises above some limit, then oil should go back to the reservoir and for that we add an pressure relief valve. What is pressure relief valve? We can set a pressure here limit pressure, which might be equal to the system pressure slightly up the system. So if there is any problem then the oil will pass through the relief valve and it will go to the tank and thus, the safety is maintained.

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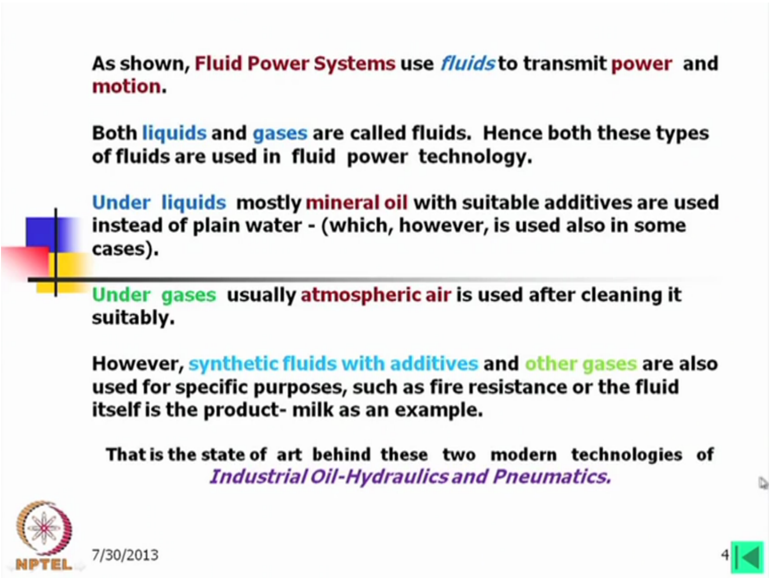

Now if we look into the industrial oil hydraulics and Pneumatics, then why it is called like this. First of all as shown in this diagram, fluid power systems use fluids to transmit power and motion that we have seen. Both liquids and gases are called fluid. Hence, both these types of fluids are used in fluid power technology. Under liquids mostly mineral oils with suitable additives, these are used instead of plain waters, which however is used also in some cases, particularly in nowadays again the water hydraulics is coming off.

The main problem with water hydraulics is that, it cannot be pressurized up to the level of the mineral oil. Also there is a problem of rasting (())(7:30). Most of the components are made of ferrous materials. So for water hydraulics we should go for some other material, anyway under gases usually atmospheric air is used after cleaning it suitably. However, synthetic fluids with additives and other gases are also used for specific purposes, such as fire resistance or the fluid itself is the product, milk as an example. That is the state of art behind these two modern technologies of industrial oil hydraulics and Pneumatics.

Now here I would like to mention in hydraulics the fluid which is used is considered as a incompressible, whereas in pneumatics should it be air or gas. This is compressible, so definitely behavior will be different as well as we have to go for separate analysis for these fluids.

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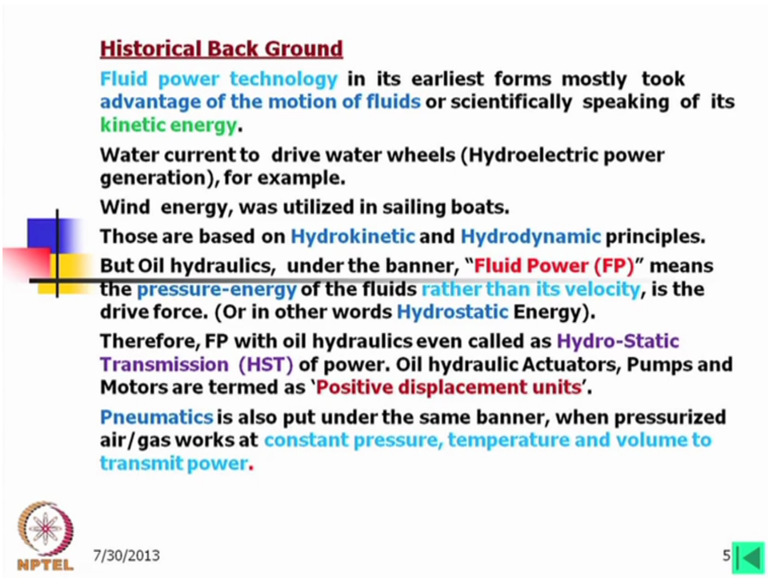

Now historic historical background is follows. Fluid power technology in its earliest form, mostly took advantage of the motion of fluids or scientifically speaking of its kinetic energy. Water current to drive water wheels example, hydraulic hydroelectric power generation as for an example. Wind energy was utilized in sailing boats. Those are based on hydrokinetic and also hydrodynamic principles, but oil hydraulics under the banner, fluid power means the pressure energy of the fluids rather than its velocity is the drive force or in other words we would say that we are using hydrostatic energy in case of fluid power. Therefore, fluid power with oil hydraulics even called as hydrostatic transmission of power. In soft form we call it HST system. Oil hydraulic actuators, pumps and motors are termed as positive displacement units.

Now here I would like to explain, let us consider an ordinary hydraulic pump centrifugal pump. There we are using kinetic energy when the impeller inside is rotating then a suction head is generated through which the fluids come in and that fluid is energized by the velocity and then it is this discharged at a pressure which may not be very high, but still we can supply the fluids with certain pressure. If we think of the turbine, there the fluids with potential energy converted into kinetic energy and that transmit the power to the impeller of the turbine and the turbine rotates, whereas in case of fluid power we supply the pressurized oil inside the actuator and it moves like it is like when it is giving the thrust to the piston, it is like a solid bar generating the thrust on it. Alternatively, if we use the rotary elements there also the same pressurized oil is working and that is why it is called hydrostatic.

A question is there do we use any hydrokinetic principle of fluids in case of fluid power, answer is yes. When we are analyzing the valve flow particularly flow in and flow out we have to use also hydrokinetic part, but as for the power transmission is concern only we are using hydrostatic power. Pneumatics is also put under the same banner, when pressurized air, gas works at constant pressure, temperature and volume to transmit power.

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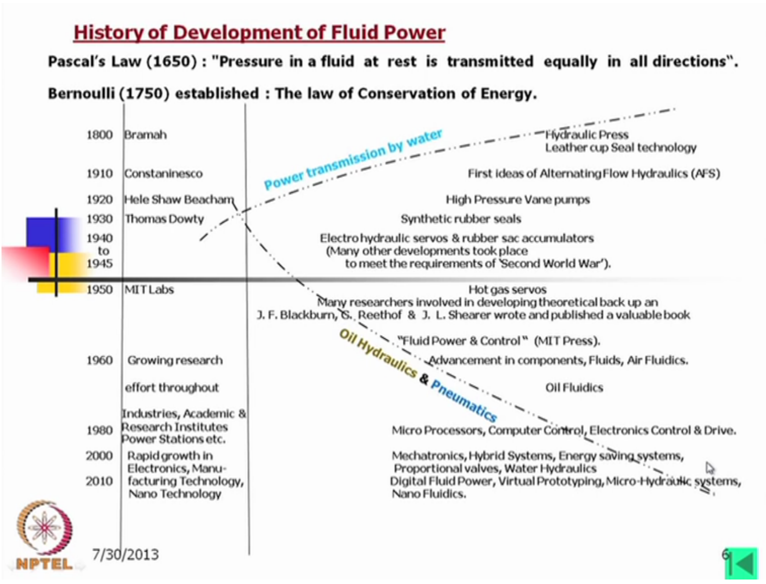

Now if we look into history of development of fluid power, then we have to go back when Pascal's invented his law in 1650 that pressure in a fluid at rest is transmitted equally in all directions. Then onwards people started thinking of the fluid power system using this fluid energy, over until the Bernoulli invented the law of conservation of energy in 1750. The fluid power did not crystalize.

Now first application of fluid power or we should say the birth of fluid power in 1800 when Bhamah an engineer develop a hydraulic press using water hydraulics. His invention was not to use the power fluid, but the leather cup seal technology. He invented a water hydraulic press. Now if we look into water hydraulics and oil hydraulics, then with time it developed. Now if I consider this line for the power transmission by water okay and in this direction, we should consider, this is the use of that fluid power. Then let us consider also oil hydraulics and Pneumatics.

Now almost after 100 year, 1900 trend that the beginning of the last century constantaninesco proposed an idea of alternating flow hydraulics. Now what it is? You know alternating electric current and direct electric current, DC system and AC system. Now in fluid power, if we have little knowledge then whatever fluid may be with few pistons, we are pumping that are mixed and then, this is transmitted to the actuator. This means that this is not alternating flow hydraulics rather, it is a direct flow hydraulics whereas, constantaninesco, he proposed the alternatic hydraulics; however that never popularized, because of his some engineering problem.

Next in 1920 Hale Shaw Beachan, he developed high pressure vane pumps as well as 1930 Thomas Dowty, he developed synthetic rubber seals. He industrialized that seal technology in fact, in fluid power as it is a high pressure technology. The main problem was the leakage, apart from some other technical problem problems. So when synthetic rubber seals were invented by Thomas Dowty, it actually the revolutionized the fluid power systems. not very far from that 1940 to 1945, there was the second world war, then to for met the requirements of world war many engineering developments took place as well as the fluid powers also started growing rapidly.

After that in 1fluid 950, MIT that is (()))(19:08) institute of technology laboratory, they in fact developed a fluid power laboratory just to give the theoretical supports to the fluid power components already being used or developed during the last few years. The outcome of that was published in a book fluid power and control which was edited by Blackburn Reethof, and Shearer all are MIT people. Now 1960 onwards, there is a rapid growth in advancement in components fluid, air fluidics, oil fluidics and many industries, academic research institute, they were also involved in research on fluid powers.

Now in between that electrical engineering devices were also developed. So it practically overs around the fluid power for the time being, but it was found that fluid power is having its own applications. So again the fluid power research and development started. Next in 1980, the rapid growth in electronics, microprocessor, computer control, electronics control and drive that were introduced and that were in fact was revolutionized again the fluid power. Now if we look into the beginning of this century, a rapid growth in electronics manufacturing technology and Nano technology has further developed this fluid power with the introduction of mechatronics, hybrid systems, energy saving systems, proportional valves again the water hydraulics, digital fluid power, virtual prototyping, micro hydraulic systems and Nano fluidics. So now we can say this subject is a combination of all engineering subjects, if we would like to know the fluid power control in better way, we have to we have to know all this subjects.

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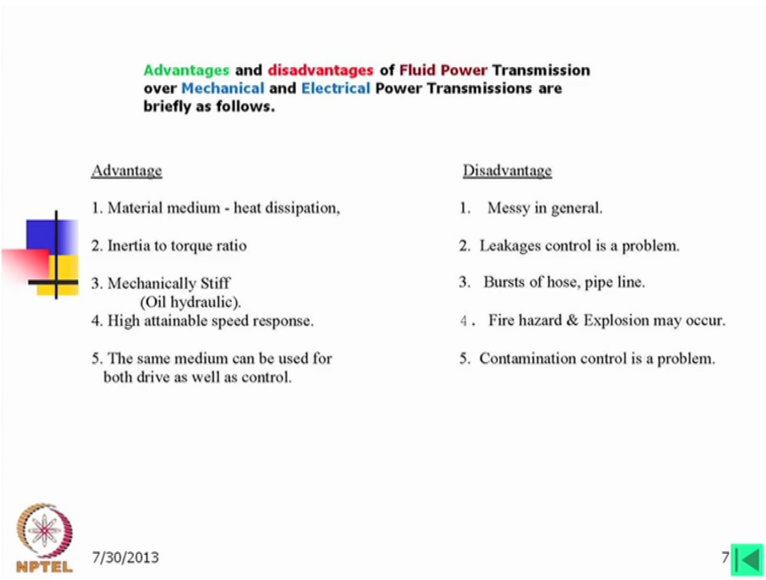

Now we should look into what are the advantages and the disadvantages of fluid power transmission over mechanical and electrical power transmission. Briefly those are advantage that material, medium and heat dissipation, it can be dissipitate easily through the body, because the fluid is spreaded all over the cavity inside. Second the second advantage is the inertia to torque ratio, as the fluid can be pressurized to a very high pressure and thus pressure can be taken by the body, because the body can be stressed highly. Therefore, inertia to torque ratio is very low in this case of fluid power that means very high torque can be transmitted at a low inertial force in comparison to electrical and mechanical devices, we shall discuss more in later.

Secondly that mechanically stiff particularly oil hydraulics, the fluid if we consider the bulk modulus, which is equivalent to the stiffness of metal, it is very high. Fourthly, high attainable speed response. The responses through the fluid is transmitted very fast. Fifth is the same medium can be used for both drive as well as control, but there are disadvantages too. Number one messy in general, second leakages control is a problem, third bursts of hose, pipeline that causes accident and we should take at most care in this regarding, apart from that in case of mineral oil, there is a fire hazard and explosion may also occur and fifth disadvantage the contamination control is a problem, because some part of the fluid power is exposed to the air and it takes out the dirt inside and cleaning this becomes a problem. There are many other disadvantages also as well as advantages, but those are minor.

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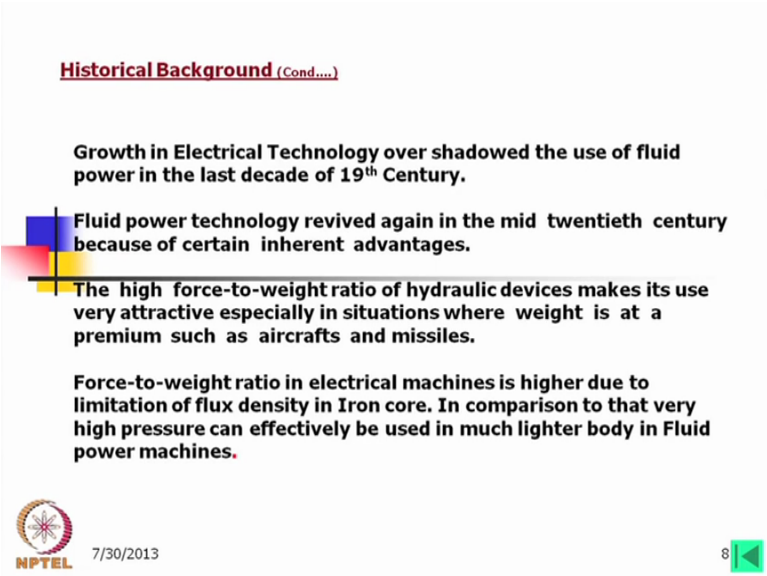

Now again we will go back to the historical background. Now growth in electrical technology over shadowered the use of fluid power which I have already mentioned in the last decade of 19th century. This is 21st century, so last decade of 19th century that time, electrical development was started and then the fluid power was setting back. Fluid power technology revived again in the mid twentieth century because of certain inherent advantages. The high force-to-weight ratio of hydraulic devices makes its use very attractive especially in situations where weight is at a premium such as aircrafts and missiles.

Now sometimes it is called force-to-weight ratio, sometime inertia-to-torque ratio, you see if we consider inertia-to-torque ratio and force-to-weight ratio, this is just a reverse. In case of fluid power devices, force-to-weight ratio is high in comparison to the mechanical and electrical devices. Force-to-weight ratio in electrical machine is higher due to limitation of flux density in iron core. If we would like to generate a torque, we have to increase to increase the torque we have to increase the flux density in iron core, but it has having own limitations.

So if we consider the flux density verses the weight that can be compared (())(27:44) to force-to-weight in case of hydraulic machines. In comparison to that very high pressure can effectively be use in much lighter body in fluid power machines, because fluid power ultimately generating stress in the body as the pressure is distributed all over tank cavity. So the body in which the fluid is being pressurized that also stressed in distributed manner and the stress level can be kept within the limit for very high pressure.

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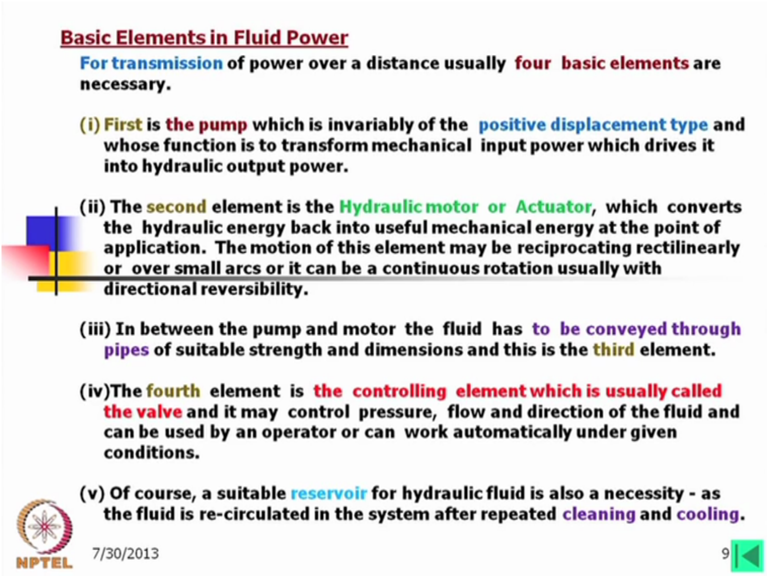

Now basic elements in fluid power, already we have seen for transmission of power over a distance usually four basic elements are necessary. First is the pump, which is invariably of the positive displacement type and whose function is to transform mechanical input power, which drives it into hydraulic output power. The second element is the hydraulic motor or actuator, which converts the hydraulic energy back into useful mechanical energy at the point of application. The motion of these elements may be reciprocating, rectilinearly or over small arcs or it can be continuous rotation usually with directional reversibility.

Now reciprocating you can easily understand that an actuator piston cylinder and also as well rotary you can understand suspend (())(29:47) type or might be piston type that can be converted into rotary motions fully, but there are also actuator which give some motion not a full rotation, but it is reciprocating in a curvilinear (()))(30:06) path. In between the pump and motor, this fluid has to be conveyed through pipes or conduits of suitable strength and dimensions and this is the third element. The fourth element is the controlling element which is usually called the valve and it may control pressure, flow and direction of the fluid and can be used by an operator or can work automatically under given conditions. Of course, a suitable reservoir for hydraulic fluid is also a necessity, as the fluid is re-circulated in the system after repeated cleaning and cooling. Nevertheless we need other components to form the finer drive or may be for some other purpose.

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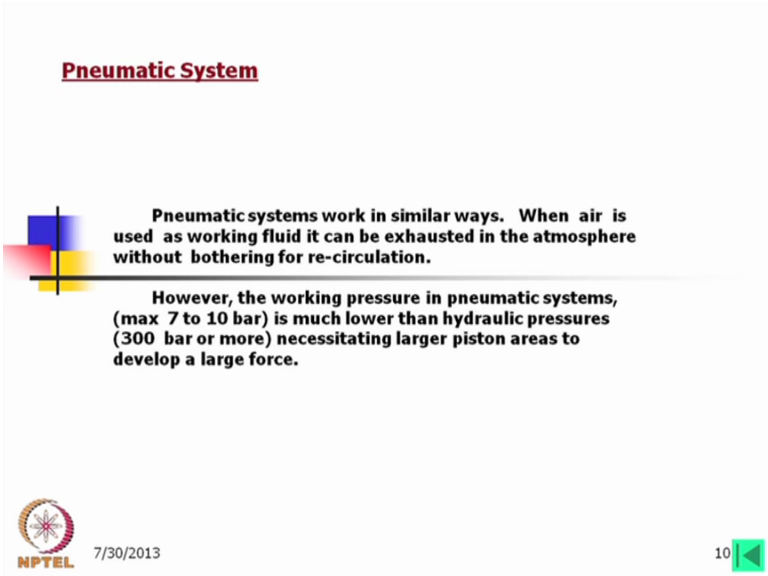

Now in pneumatic system, it works in similar ways. When air is used as working fluid, it can be exhausted in the atmosphere without bothering for re-circulation. This means that in case of pneumatic, if we filter the air to come in then we need not bother about the re-circulation, because it is exhausted to the atmosphere. It has other advantages; however the working pressure in pneumatic systems is usually 7 to 10 bar is much lower than hydraulic pressures, which 300 bar or more. Therefore, for pneumatics we need larger piston areas to develop a large force. So if we think in this way, we will find that pneumatic under the fluid power banner, it has the separate applications, than the hydraulics under the fluid power banner. Normally hydraulics are used to transmit very high power and pneumatics are used for the small actuation and control.

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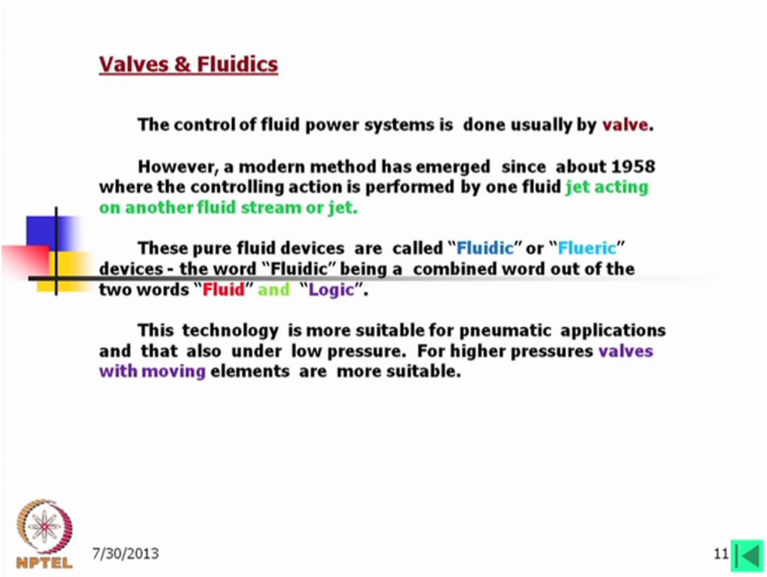

Now valves and fluidics. The control of fluid power system is done usually by the valve, which we have mentioned earlier. However, a modern method has immerged since about 1958, where the controlling action is performed by one fluid jet acting on another fluid stream or jet. The pure fluid devices are called fluidic or flueric devices. The word fluidic being a combined word out of the two words fluid and logic. This means that the fluidic devices also can be used as a valve, however initially the fluidic devices was only pneumatic. Therefore, it was being used for mostly signaling not the valve where we need the larger force. However, where the pneumatic was used, there we could use the fluidic devices also as a valve. This technology is more suitable for pneumatic application, which I have mentioned and that also under low pressure. For high pressure valves with moving elements are most suitable.

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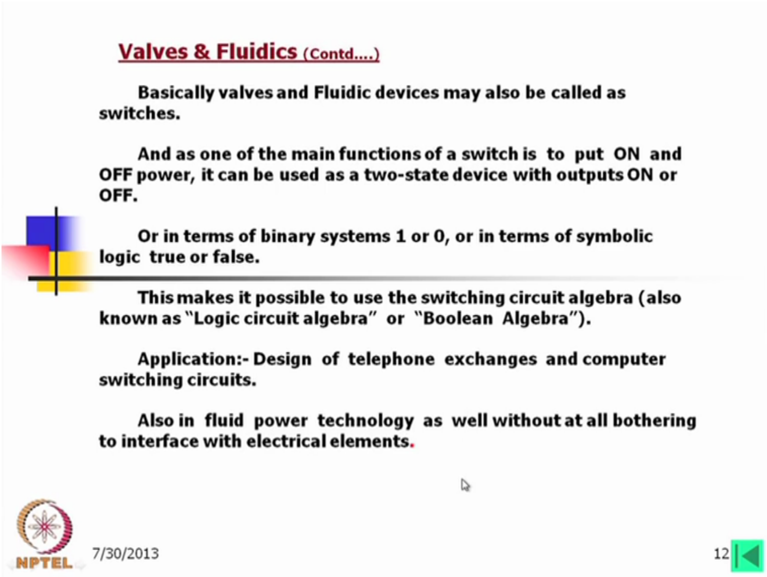

Now we continue this with, basically valves and fluidic devices may also be called as switches. And as one of the main functions of a switch is to put on and off power, it can be used as a two state device with outputs on or off or in terms of binary system one or zero or in terms of symbolic logic true or false. This makes it possible to use the switching circuit algebra also known as logic circuit algebra and Boolean algebra. We will learn this topic separately in a different lecture later in this course. Application design of telephone exchange and computers, switching circuits where we use this logics. Also in fluid power technology as well without at all bothering to interface with electrical elements.

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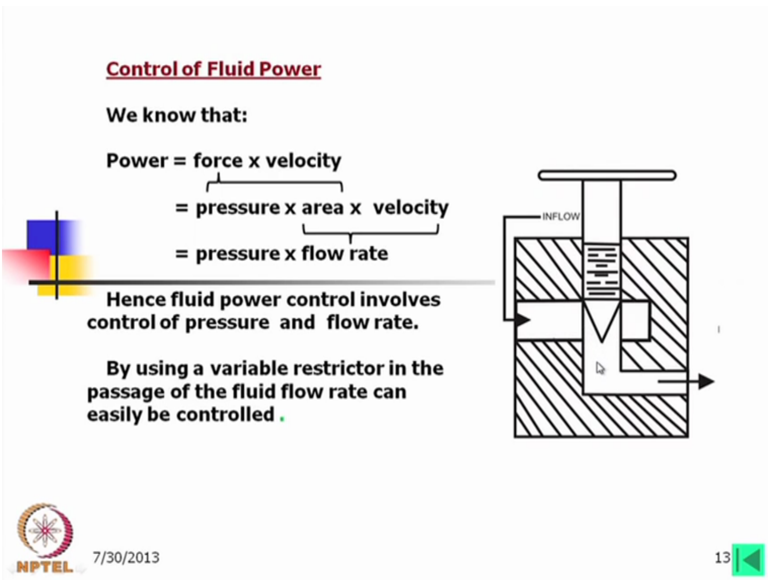

Now control of fluid power, we know that power is equal to force into velocity. Now the force can be resolve into pressure into area, then velocity. Then we can write pressure into flow rate, which is the output of a pump, but we should remember, the pump output is the flow rate not the pressure. Pressure is experienced by the load we are transmitting or the motor torque to transmit the load. Hence, fluid power control involves control of pressure and flow rate. By using a variable restrictor in the passage of the fluid flow rate fluid flow sorry fluid. Flow rate can easily be controlled. Now this is a valve which is shown. This is very schematic view, but what I find the flow is going in and there is something like screw, which is restricting this path. Now this by doing so what we can do, we can control the flow as well as pressure.

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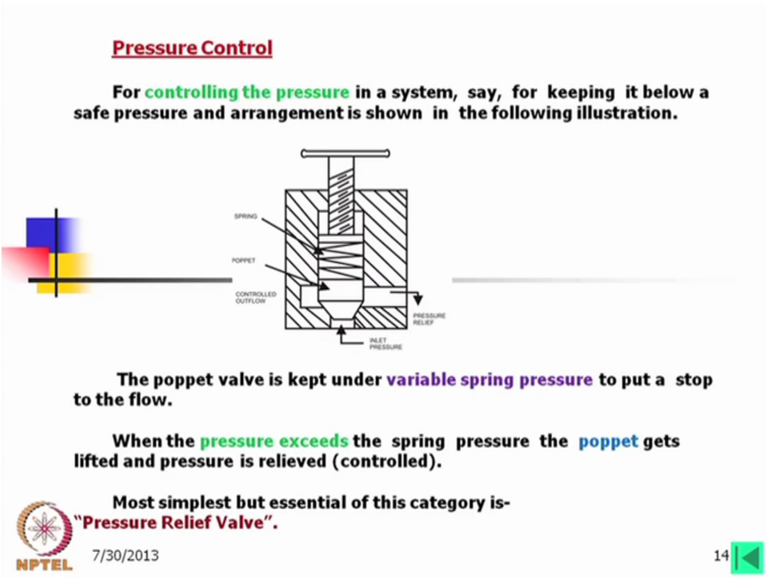

Now pressure control is done for keeping it below a safe pressure and arrangement is shown in the following illustration. Now in this case what is there? The flow if we look into this figure flow is going in from the bottom and then as if there is a body, which is called poppet. It is under a pressure of a spring the length of this spring again can be controlled by a screw. So what happens when there is a certain pressure only then this opens and fluid can go out otherwise normally, this flow is going to a system. So this is the basic concept of pressure relief valve.

The poppet valve is kept under variable spring pressure, which I have described to put a stop to the flow. When the pressure exceeds the spring pressure, the poppet gets lifted and the pressure is relieved or we can say, it is controlled. Most simplest but essential of this category is pressure relief valve. In fact the pressure relief valve to be used in all fluid power system for the purpose of safety.

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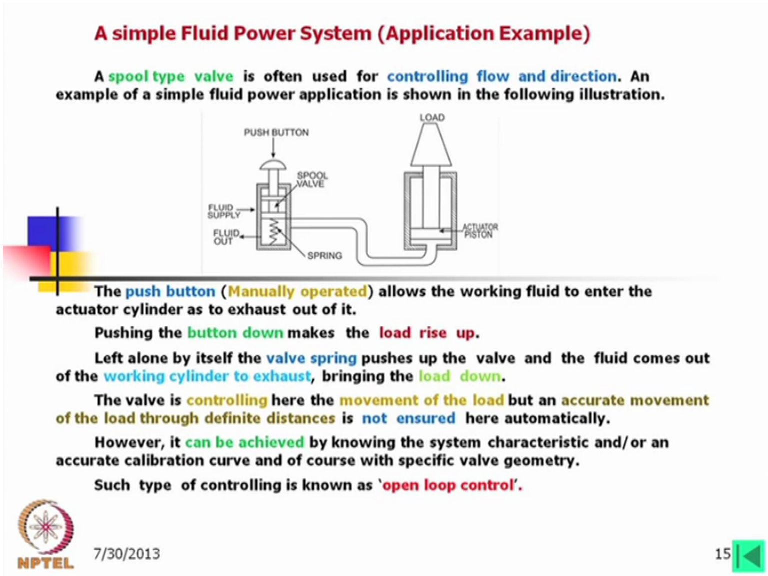

A simple fluid power system application example is that. A spool type valve is often used for controlling flow and the direction. An example of simple fluid power application is shown in the following illustration. What is there we find? A load is being lifted and there is a valve. This valve is a simple push button type. Now fluid supply is air. Now if we push down then this fluid will go to the step. Now if we again remove the pressure on the push button, then this fluid will go out, which I have already described.

The push button allows the working fluid to enter the actuator cylinder as to exhaust out of it. Pushing the button down makes the load rise up and left alone by itself the valve spring pushes up the valve and the fluid comes out of the working cylinder to exhaust, bringing the load down. The valve is controlling here, the moment of the load, but an accurate moment of the load through definite distance is not ensured here automatically. However, it can be achieved by knowing the system characteristics and/or an accurate calibration curve and of course with specific valve geometry. This means that we can control this valve to get an say desire rate of flow etcetera by controlling orifice (())(41:50). Such type of controlling is known as open loop control.

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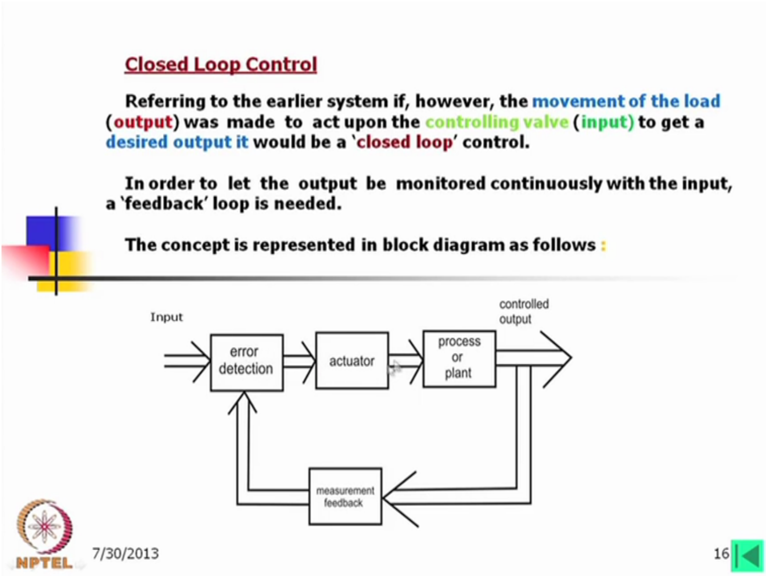

Now what is closed loop control in fluid power? Referring to the earlier system if, however the moment of the load was made to act upon the controlling valve to get a desired output, it would be a closed loop control. In order to let the output be monitored continuously with the input, a feedback loop is needed. The concept is represented in the block diagram as follows. Now what is there, an input, then error detection, then actuator, process or plant, then controlled output and there itself a feedback, which is coming to the error detection and then it is controlling the actuator.

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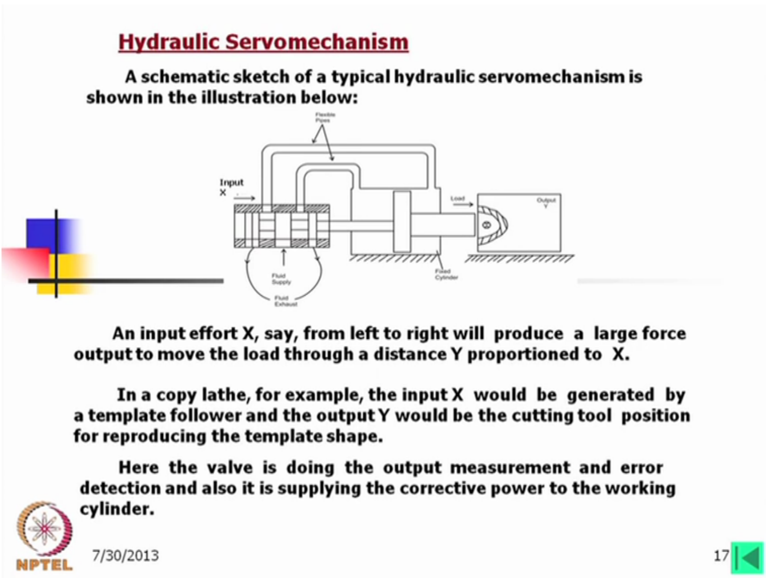

Now we can think of the servo mechanism, which is also with hydraulic. The servo term as you know, it is feedback control of motion and position. So a schematic view is shown here.

This is the load, it is being moved with an actuator and there is a valve. Now the system is like that when we give an input then load moves, but looking into position and motion, the valve body outside body also moves and by that closing the motion of the load and again with the presence of input, the spool will move further and load will be move load will be moved. Now if there is an feedback control within the system, then we shall call it servo mechanism and there is a wide application of hydraulic servo mechanism starting from the machine tools to many other say even if it is in the missile control.

Now here this is further explained as like that. An input effort X, say, from the left to right will produce a large force output to move the load through a distance Y proportional to X. in a copy lathe, for example, the input X would be generated by a template follower and the output Y would be the cutting tool position for reproducing the template shape. Here, the valve is doing the output measurement and error detection and also it is supplying the corrective power to the working cylinder.

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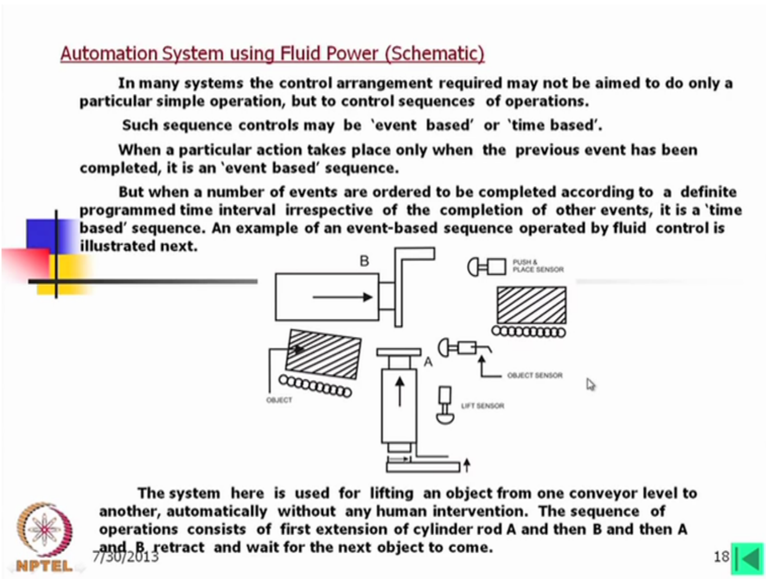

Now automation system using fluid power, it is a schematic view is presented here. In many systems, the control arrangement required may not be aimed to do only a particular simple operations, but to control sequences of operations. Such sequence controls may be event based or time based that means looking into the event. This control is being operated or may be on time. When a particular action takes place only when the previous event has been completed, it is an event based sequence, but when a number of events are ordered to be completed according to a definite programmed time interval irrespective of the completion of other events, it is a time based sequence. An example of an event-based sequence operated by fluid control is illustrated next.

Now look at this. The system is here is used for lifting an object from one conveyor level to another, automatically without any human intervention. The sequence of operation consist of first extension of cylinder A rod and then B and then A and B retract and wait for the next object to come. See it is like that an object is coming in, then with this cylinder this is lifted to this conveyor. What is there when this load is coming in, then this object sensor is there which is sensing the object is on this A cylinder, then this will be lifted and there another lift sensors, which will give an indication to the cylinder B and that will be push to this conveyor and when this push will be completed, it will push another sensor which will go back to the again initial state, that means another object will come. So this is a simplified schematic view, but actual will be very complicated and designing these are all may be with fluid power. These actuators are using the fluid power, sometimes these are with the fluid power or with electronics.

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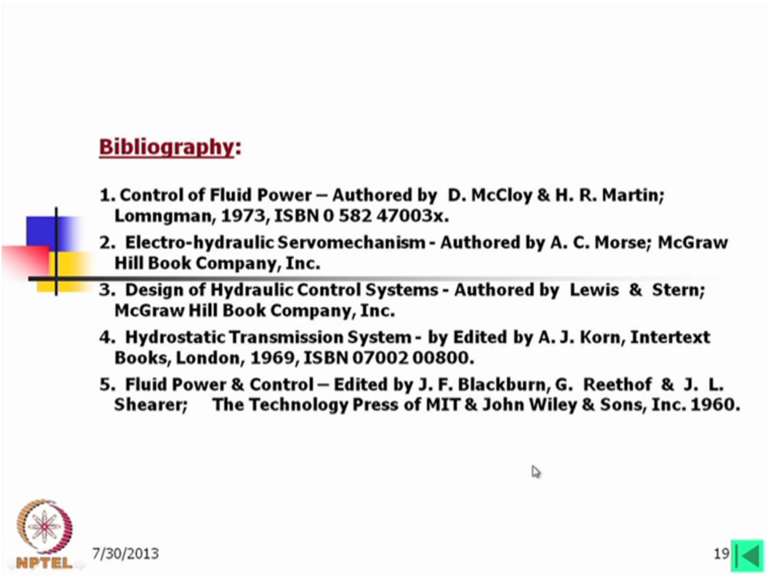

Now this lecture is prepared with following these books and these are mostly books, one is the control of fluid power authored by Mccloy and Martin. This is a very good book. Now electro-hydraulic servo mechanism by Morse also an important book. Similarly design of hydraulic control systems. Hydrostatic transmission system by Korn. This is available in our library and lastly, I have followed also fluid power and control by Blackburn, Reethof and Shearer, which I have mentioned earlier.

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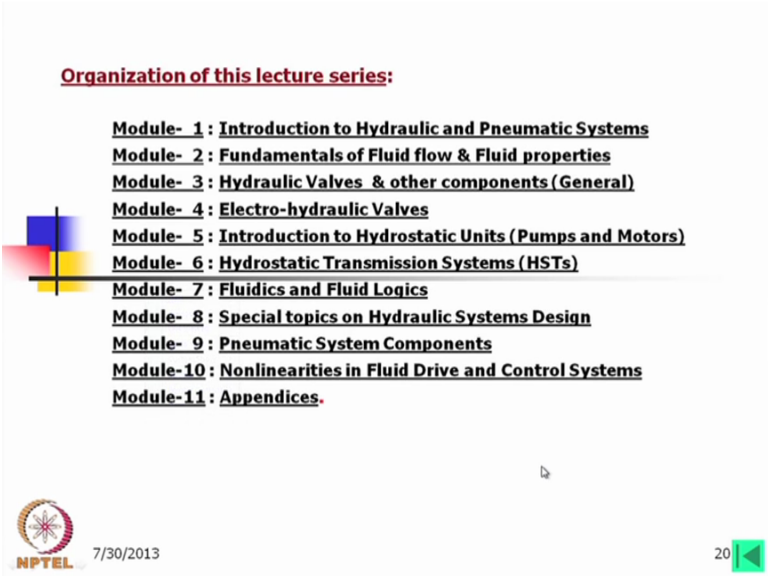

Now organization of this lecture series. So this was the introductory lectures. So first lecture. Now module one will be introduction to hydraulic and pneumatic systems. There are few modules, I will describe one after another and each module is having minimum 2 to 4-5 lectures. Now our next module will be the fundamentals of fluid flow and fluid properties. Next one module 3, hydraulic valves and other components, module 4 electrohydraulic valves. Module 5 introduction to hydrostatic units pumps and motors. Module 6 hydrostatic transmission systems, module 7 fluidics and fluid logics, module 8 special topics on hydraulic systems design. Module 9 pneumatic system components, module 10 nonlinearities in fluid drive and control systems and last is appendices. This is actually miscellaneous things, may be sometimes some problems are solved there as well as in many lectures you have to follow the appendices for the further study of that portion. However, we shall go one after another, but sometimes it might be that we can jump to other module instead of continuously following the sequences and that is all. Thank you very much for listening.