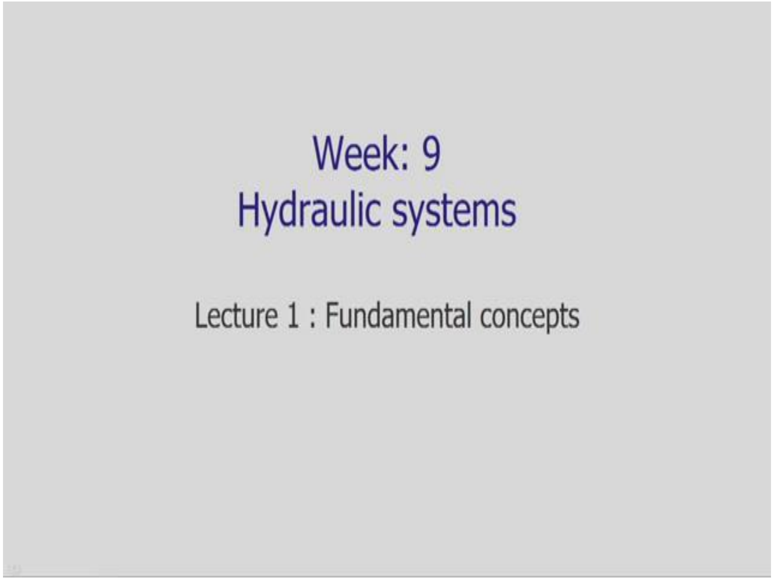
Automation in Manufacturing

Dr. Shrikrishna N. Joshi
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

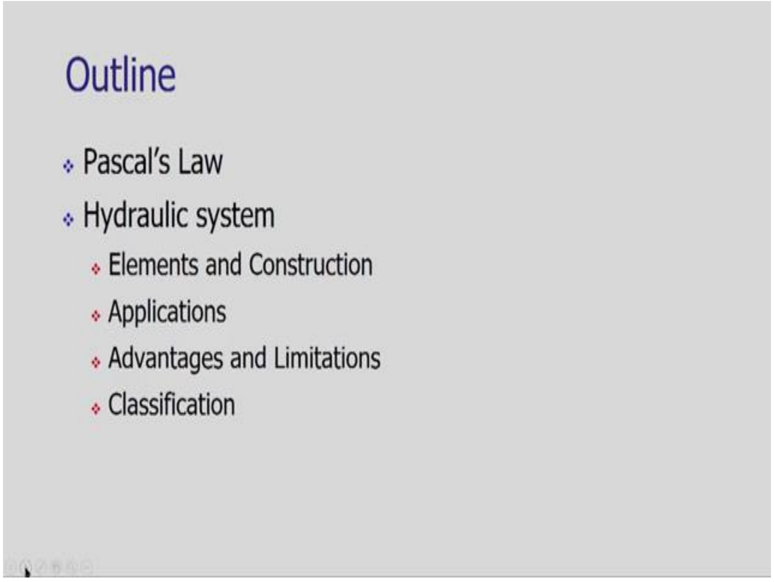
Week – 09
Hydraulic Systems
Lecture – 01
Fundamental Concepts

(Refer Slide Time: 00:46)



Hello and welcome you all to the week 9 of Automation in Manufacturing. The week 9 is dedicated to the study of Hydraulic Systems, which are used in automation industry. In previous weeks, we have seen electrical drives, hydraulic drives and pneumatic drives are also used to carry out variety of production operations in the automation. We will be learning the fundamental concepts in the 1st lecture of this week.

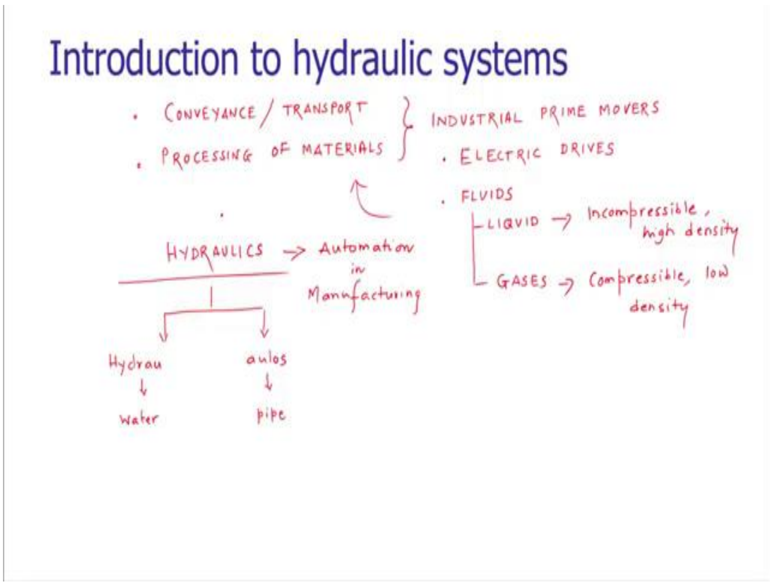
(Refer Slide Time: 01:16)



Let us look at the outline of this lecture. At start of the lecture, we will be studying the Pascal's law on which the hydraulic systems are working. Then we will have a study of various elements of a typical hydraulic system, the construction of a hydraulic power pack.

We will study various applications in the automation. After that we will have a discussion on the advantages and limitations of the hydraulic system. At the end of the lecture we will have the classification of hydraulic systems. Let us begin the lecture 1.

(Refer Slide Time: 02:05)



In industry we required the energy to carry out basically two functions, that is conveyance or transport and processing of materials. And to carry out these operations whatever the systems are required in terms of the energy are called as industrial prime movers. We have seen one industrial prime mover that is the electrical drives in our previous weeks.

Electrical drives are very widely used in the industry to convert the rotary motion into the translatory motion or even the rotary motion itself can be utilized to carry outs variety of operation. In addition to the electrical drives we are also using fluids to carry out these operations.

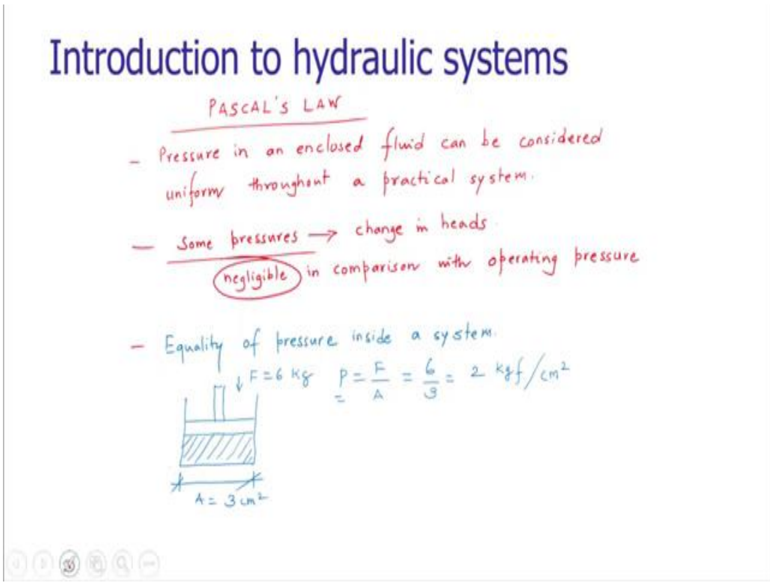
Fluids are required when we want to have a very huge amount of energy, very huge amount of power which may be for the processing or it may be for holding, the load at it is position. When, we are using fluids such as the liquid or the gases to carry out the operation.

In liquid it may be oil or the water is used or in gases we are using the compressed air for variety of applications. Liquid as we know it is incompressible, but it has high density in comparison with gases. The gases are compressible; however, they are having low density in comparison with hydraulics. Both these forms of the fluid can be utilized effectively to carry out these two operation that is a conveyance and the processing of materials.

In this particular week, we are studying the hydraulics and hydraulic systems, which are required in our purpose that is automation in manufacturing. Basically the word hydraulics has come from Greek. It has two terms; first term is hydrau and the second term is aulos. Hydrau means water whereas, aulos means pipe.

The system which is comprising of a pipe and the system, which is flowing or transporting the water through the pipes. All the aspects related to the flow of water through pipes is made, it may be fluid low pressure, it is application so on and so forth. The aspects or the studies of various elements of water flowing through pipes is called as the hydraulics.

(Refer Slide Time: 05:55)



The hydraulic systems are working based upon a law and that law is Pascal's law. The Pascal's law states that, pressure in an enclosed fluid can be considered uniform throughout a practical system. In a practical system, if, we are using an enclosed fluid the pressure can be considered as uniform throughout the entire system.

That has been suggested by the Pascal and which is the basic principle of all the hydraulic systems, but in a typical system we may have some pressures due to the change in the head. We can say there are some pressures that may be generated due to change in heads.

However, this pressures are negligible. They are very small in comparison with the operating pressures. The operating pressures in the hydraulic systems are very huge and very large as we have seen that 150 bar. In comparison with these the heads, which are generating the pressure it is quite small. We can certainly neglect them or in a simplified word we can say that, this equality of pressure inside the system is nothing, but the Pascal's law, equality of pressure inside a system.

To understand it in a better way let us take an example. Consider we are having open system. Now, let us make it close so we are using a container and then the container has a piston and there is liquid, which is filled in the container and over the liquid, we are having a piston.

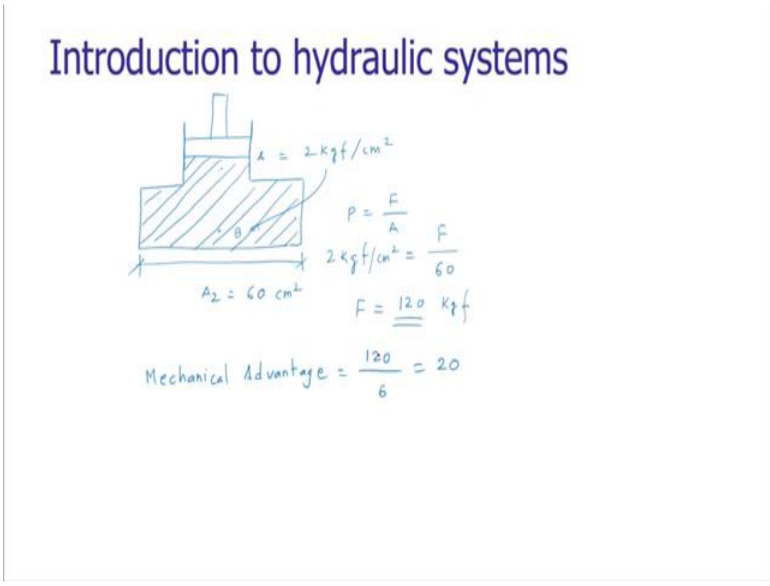
Consider we are applying a force (F) of 6 kilogram. F is equal to 6 kilogram. And, the area over which we are applying that is considered this area is equal to 3 cmcm^2. What we are getting here? The pressure (P) is equal to:

$$P = \frac{F}{A}$$

and that is coming around 2 kgf/cm^2.

As per the Pascal's law, the pressure of 2 kgf/cm^{2}is uniform inside the system. 2 kgf/cm^2 is the pressure applied by the fluid over valves of the system.

(Refer Slide Time: 09:40)



Let us consider we are having the change in the geometry. Consider we are just adding 1 more container to the previous container whose area is larger than the previous container. Let us consider, the same container with the piston arrangement has been enlarged and a fluid is filled inside the system.

Now, as per Pascal's law, the pressure here a point A is 2 kgf/cm^2. The same pressure would be there in a point B, which is in the bottom portion of the system as well. So, here as well the pressure is 2 kgf/cm^2. However, the area has been increased now; the area of application of this pressure is increased.

As the area of application has been enhanced what thing we are getting hereI if I use the same correlation?

$$P = \frac{F}{A}$$

the pressure is 2 kgf/cm^2 , we have need to find out how much is the force, which is being generated.

Area now let us consider it has been increased. The area is increased to around 60 cm^2. If we use the area as 60, the force applied would be around 120 kgf. The meaning is that if we increase the area of application, the force is getting increased. This same principle can be used to carry out our operation.

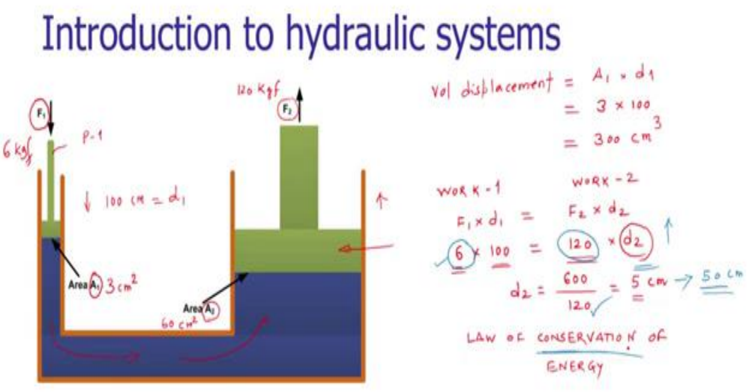
Here we notice an application of 6 kg at the top surface. The 6 kg at the top surface in container A is generating around 120 kgf at the bottom side of the container. Meaning is that there is enhancement in the application of the load, that we call the mechanical advantage. By application of 6 kg we are generating 120 kg.

The mechanical advantage which is generated here is:

$$\frac{120}{6} = 20$$

. 20 times we have enhanced the input force and this arrangement; this peculiarity can be utilized to carry out variety of operations in the hydraulic system.

(Refer Slide Time: 13:16)



Now, let us see how we can utilize this mechanical advantage in the engineering applications? For this purpose, let us redraw the diagram, which we have seen in the previous slide. We considered F_1 as 6 kgf the area A_1 of 3 cm^2, area A_2 was 60 cm^2 and we computed the force F_2 as 120 kgf.

Now, the system is in equilibrium. If we push the piston P_1, by say around 100 cm in downward direction , there would be a volume displacement, the fluid which is there in this area or the on the left side of the system will get displaced. We would will get displaced and it will go to the right side.

The volume can be computed:

$$Vol\ displacement = A1 \times d1$$

$$= 30 \times 100$$

$$= 300\ cm^3$$

This volume will be applied on the right side of the system due to the displacement of this volume, there would be lifting of the force F_2, there would be displacement of the piston at the part 2. This lifting can be computed by using the law of conservation of energy.

As we know, that whatever the energy that we are spending, whatever the work done that we are doing or whatever the work done we are inputting that would be just converted into the another form. The energy is getting conserved, it is getting just transferred from or it is transformed from 1 form to the another form.

Work 1 = Work 2

F_1 x d_1 = F_2 x d_2

6 x 100 = 120 x d_2

d_2 = 5 cm

That is interesting to know that, there is magnification of the force from the left to right, 6 is getting enhanced, it is a magnification from 6 to 120 kgf, but there is a reduction in the displacement. The reduction is from 100 cm at the left to the 5 cm of the right side of the system. This follows basically the law of conservation of energy. What is our interest here?

If we notice, we are applying 6 k g and we are generating 120 kgf force in the system in the other part of the system; that means, there is a magnification; however, the displacement is less. To have the increase in the displacement to have the desired high level of the displacement for example, the 5 cm we are expecting to increase that to the 50 cm.

Meaning is that, to generate a displacement of 120 kgf of the force from 5 cm to the 50 cm. In that proportion we have to apply the pressure that in that proportion, we have to apply the input energy. But our cylinder is small, 6 kgf force we are applying. The system input system is able to apply only the 6 kgf. In that case we have to increase the displacement.

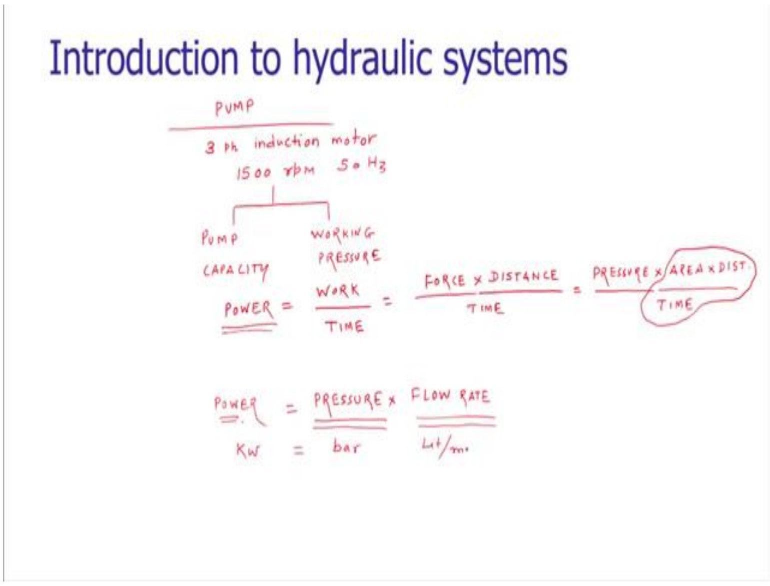
Instead of having only 1 time application of 100 cm, we have to apply around 10 times application of the 100 cm. Means the 10 strokes fluid is to be pushed in the right side of the part of the system to get the 50 cm displacement of the F_2.

That same principle is applied in the hydraulics. We are making the system compact, we are making the input compact, but we are applying that small input for number of times. And, that increase in the frequency of application of the input will be generating the desired results. We can have a small system which is giving the input of 6 kg, the displacement is 100 cm, but it is producing a result of 120 kgf, the displacement is small.

We push in for 10 times of this 6 kgf for 100 cm stroke at the left side of the system, it can easily generate a 50 cm displacement of 120 kgf of the load. A small system is driving a big system. The small portion of the system is driving a big system to the application of the energy would be constant.

We are conserving, we need the energy only the thing is that we can have a system, which can be easily operated easily handled. That is nothing but the hydraulic system. Let us look at what are the various components of the hydraulic system in our coming slides.

(Refer Slide Time: 21:30)



The main element in hydraulic system is the hydraulic pump. In general the hydraulic pump is driven by a 3 phase induction motor, which we generally operate at 1500 rpm and at 50 Hertz. The pumps are characterized or the pumps are specified by using 2 parameters; the first one is pump capacity and the second one is the working pressure.

In general we are computing the power as the work done per unit time. The power which is being generated by mechanical system is nothing, but the work per minute time work divided by time, as we have seen that the work done carried out by a hydraulic system is nothing, but the product of force and displacement.

Force we know that, it is product of the pressure and area of application, or here we can just write:

$$Power = \frac{Work}{Time} = \frac{Force \times Distance}{Time} = \frac{Pressure \times Area \times Distance}{Time}$$

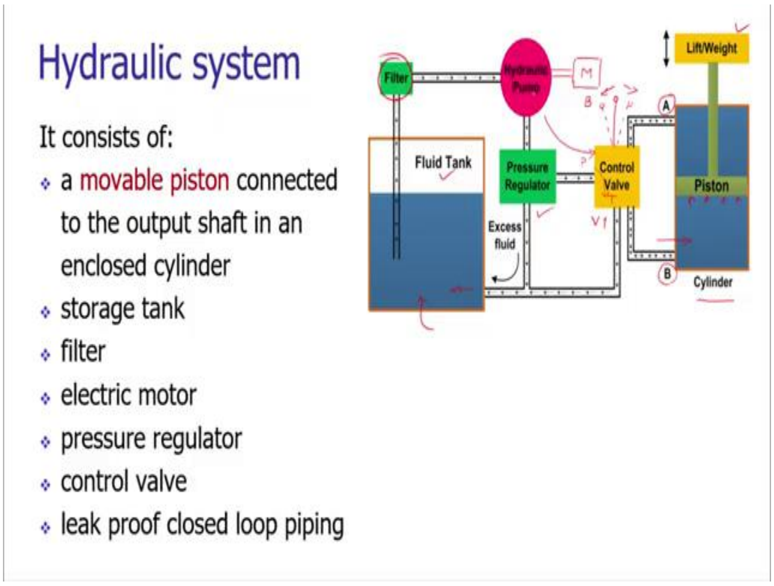
If we consider the product of area and the distance is nothing, but the volume of the fluid that is getting displaced. Thus we can write:

$$Power = \frac{Pressure \times Area \times Distance}{Time} = \frac{Pressure \times Volume}{Time}$$

$$= Pressure \times Flow\ rate$$

Hence, the power capacity or the power requirement or the powers characteristic of a hydraulic system is the pressure being handled by the hydraulic system and the flow rate. The pressure is the working pressure of the system and the flow rate is it is the capacity the pump capacity. Basically, the power is given into the kilowatt, the pressure is defined in bar and the flow rate is defined into the litre per minute.

(Refer Slide Time: 25:18)



Let us look at what are the various elements of a hydraulic system. We have seen that in general the hydraulic systems are used to apply the load we have or we have to hold. The load on our screen, we can see a schematic, where a task is there and that is the task of lifting a weight, task of lifting a load.

For that purpose, we are using a piston cylinder arrangement, the actuator and the weight is applied over here, weight is applied over a piston cylinder arrangement. We need the pressurized fluid and that pressurized fluid is stored in a tank and the hydraulic pump is drawing the fluid from the fluid tank and that will put in the piston cylinder arrangement to get the required work done. It may be the lifting or the lowering of the load.

The hydraulic pump is managed or it is driven by motor, we need electrical motor. The hydraulic pump is drawing the fluid from the fluid tank, it is increasing it is pressure and that pressure will be applied at the bottom portion of the piston, to increase the extension of the piston rod.

For that purpose, to have the control of the direction of fluid flow, we need certain arrangement and that is nothing but the control valve. We can control the direction by using a control valve, we can change the direction of the fluid flow by operating the valve.

We can have the three position control of the control valve. Let us considered control valve V 1 is at it is the normal position that is the closed position. Tthere is no fluid which is flowing in port A and there is no fluid which is flowing in port B. If, we want to raise the load, so then you can just operate the valve, so you can operate the valve to open the port B.

As you open the port B the fluid is flowing at this side and we can lift we can lift or we can raise the load in this case. To lower the load, we have to operate the side B of the control valve, so that the pressurized fluid will be applied on the other side of the piston and in this way we can lower the load.

If, we are at the central position at the normal position and the system pressure will increase, because a continuous pressurized fluid is being flow in inside the system due to the continuous operation of the hydraulic pump. That increase in the pressure will definitely harm the system.

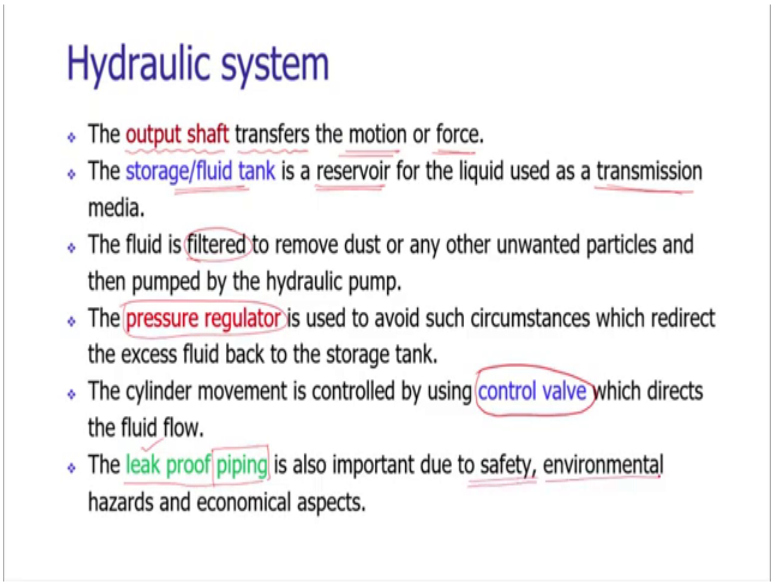
For that purpose we have to spill out the excess pressure pressurized fluid from the system. Ffor that purpose we are using a pressure regulator. In this case, if the fluid pressure is more than the critical pressure the excess fluid will be passed through the pressure regulator valve and it will get back to the fluid tank.

When the control valve it is normal position, in that case as well there is a port, that is a tank port, the from the power port we are getting the pressurized fluid. And, that pressurized fluid will directly be passed to the tank port through which the excess pressurized fluid will be taken back to the fluid tank.

In this way there are various elements those are helping to have an efficient operation of the hydraulic system. In hydraulic system we also face the problem of the dirt or we also face the problem of inclusion of some dust particles. That dirt or the dust particles will harm the system.

For that purpose we have to filter the operating fluid that is whatever it may be the water or it may be some special oil. We have to filter it out to protect or to enhance the efficiency of the hydraulic pump.

(Refer Slide Time: 30:56)

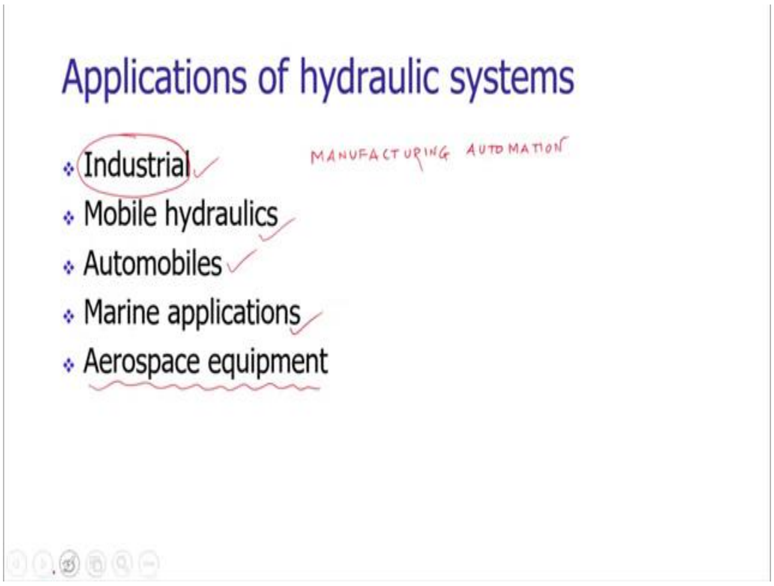


Let us summarize. In hydraulic system we need an output shaft, which is used to transfer the motion or the force. There is a reservoir and that reservoir is storing the fluid, which is used as the transmission media.

We need to filter out the dust or the unwanted particles that are to be pumped inside the system. We need to have a pressure regulator to avoid the circumstances in which there may be the failure of the system due to the excess pressure.

There is a control valve and that control valve is controlling the direction of fluid flow inside the system. In addition to the controlling elements, we also need the transportation elements and these are the piping. The piping’s must be leak proof to have the high efficiency of the hydraulic system. The piping’s should be leak proof to have the safer operation and less environmental hazards.

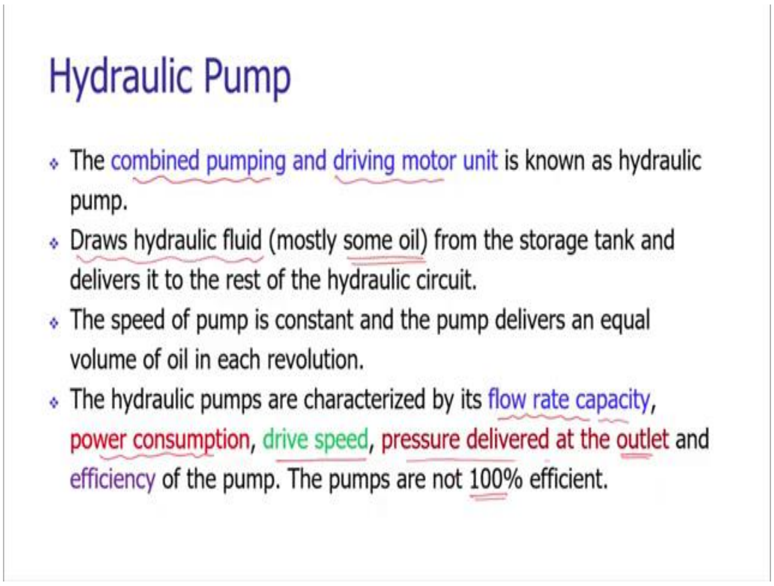
(Refer Slide Time: 32:21)



The hydraulic systems have variety of applications in manufacturing industry, in mobile hydraulics. It is meaning an excavators or the earth moving equipment, they are working based on the hydraulics. In automobiles in a shock absorber, we are using the hydraulic systems.

In marine applications also we are using the hydraulics; in aerospace equipment also we are using the hydraulic systems. As per as the course is concerned we are more focused upon the pumps or the elements which are required for the industrial manufacturing. In the context of this present course, we are more focused upon the application of hydraulic systems in manufacturing.

(Refer Slide Time: 33:24)

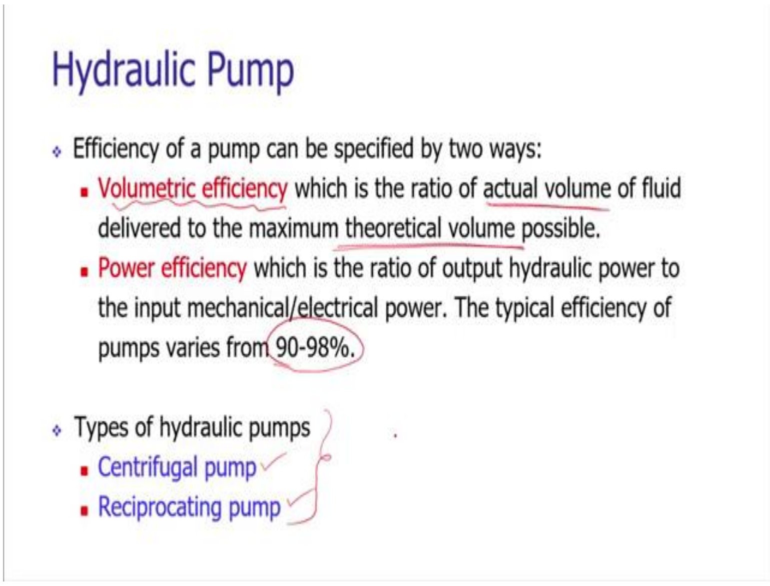


The hydraulic pump is the combined pumping unit; it is having the driving motor as well. As we have seen that it is drawing the hydraulic fluid mostly some oil from the tank and then it is delivering that to the rest of the hydraulic circuit.

In positive displacement pumps the speed of the pump is constant and the pump is delivering an equal volume of oil in each revolution, but in hydrodynamic pump the volume of the delivery is varying it is not constant.

In general, the hydraulic pumps are characterized by the flow rate capacity, power consumption, drive speed, pressure that to be delivered at the outlet, and in general the hydraulic systems are having very good efficiency, but certainly not the 100 %t efficiency.

(Refer Slide Time: 34:32)

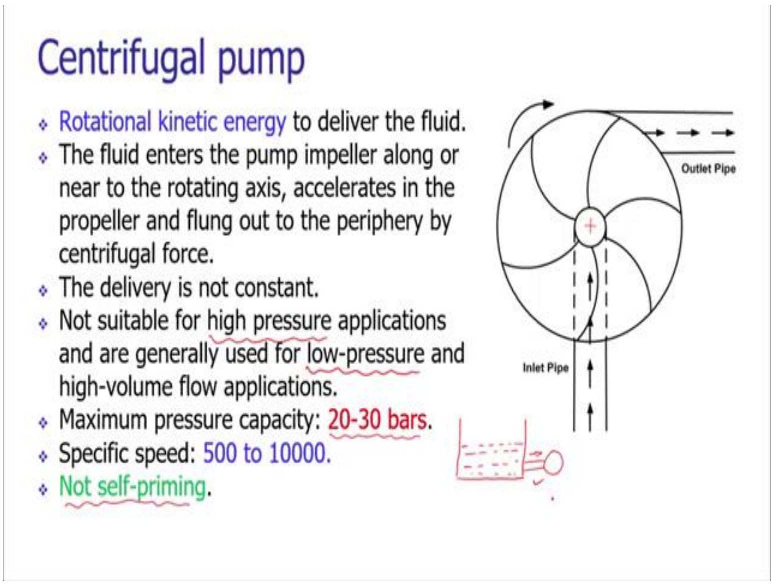


We can define the volumetric efficiency of a hydraulic pump as the ratio of the actual volume of the fluid delivered by the system to the theoretical volume possible. By theoretical we are computing based upon the correlations that we have seen in the previous slide, but in actual sense these things are not possible, due to the inherent problems of the systems due to certain. Errors due to having the incapability or the manufacturing errors of the pumps itself.

Volumetric efficiency will not be 100 %. I it could be less than the 100 %. The power efficiency is also not 100 %, but the hydraulics they are generating around 90 to 98 %t of the power efficiency. The power efficiency is defined as the ratio of the output hydraulic power that we are getting to the input mechanical or the electrical power.

In general, two types of pumps are used these are the centrifugal pumps and the reciprocating pumps, we will be studying about them in the next slides and in detail in the next lecture.

(Refer Slide Time: 35:58)



The centrifugal pump is very widely used in the domestic water distribution, domestic water handling. It is using the rotational kinetic energy to deliver the fluid the, typical arrangement of the centrifugal pump can be seen on your screen.

There is an inlet pipe, there is a circular disc or over the circular disc, we are having the impellers and there is a output pipe. The fluid is entering the pump impeller along or near to the rotary axis. This is the axis of the impeller and the fluid is coming at the center or near the center of the rotating disc which is having the impellers.

The impellers are driven by an electric motor, a rotary motion is given to the impeller disc. And, as the impeller disc is rotating due to the centrifugal force the fluid which is coming inside the system will be plunged out. It will be moved in a radial direction outward direction and in this way we are increasing the pressure of the fluid. The delivery or the volume delivery of the centrifugal pump is not constant it is varying.

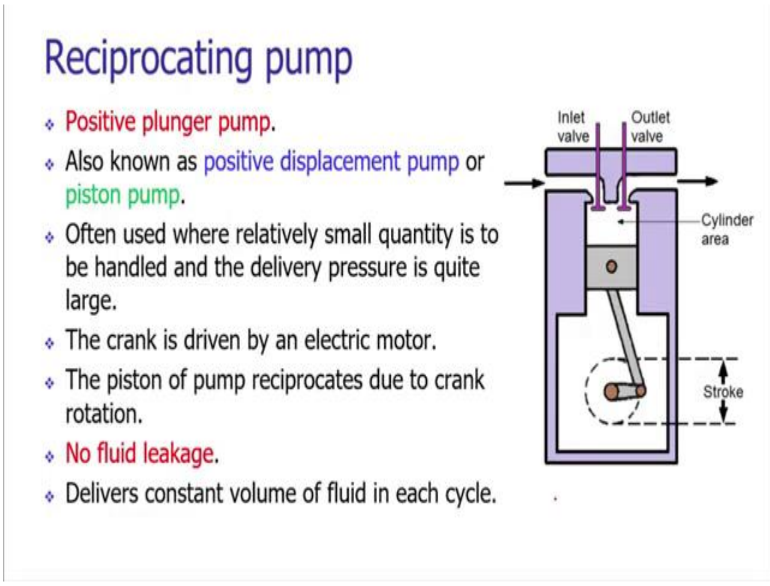
It is not that suitable for the high pressure applications, these are not consistently developing the pressure as well. So, these are in general used to deliver the high volume fluid at the low pressure. In general, we are using the centrifugal pumps for around 20 to 30 bars. The centrifugal pumps are not self-priming. Ppriming is a process where the pumps are having the capability to get in the fluid inside the system.

Consider there is a tank and the tank has the fluid and there is a pump, which is attached here this is the pump, the pump by the gravity itself. There is no need to push, or there is no need to have any mechanism, to get the fluid inside the pump, that is called as the self-priming.

This is fine way in case of this kind of situation when the level of the fluid, inside the system and the level of the pump inside the system at the same or the pump is at the lower level than the storage tank.

In case the pump is located at certain height. There is some lifting is to be carried out, the initial lifting of the fluid at the start of the operation of the pump is called as the priming. That facility or that capability is not there in the centrifugal pump. We have to have the manual or additional mechanism to prime the pump to add the extra fluid inside the pump.

(Refer Slide Time: 39:32)



The second broad category is the reciprocating pump or the second important pump is the reciprocating pump, that is called as the positive plunger pump as well. These kind of arrangements are producing small quantity of the pressurized fluid in each stroke the arrangement can be seen on our screen.

It is having a cylinder area there is a piston, the piston is having connecting rod, then there is a crank, crankshaft, at the top of the cylinder there are two openings. And, these two openings are having valves, that is the inlet valve and the outlet valve the inlet valve has the inlet port and the outlet valve is having the outlet port.

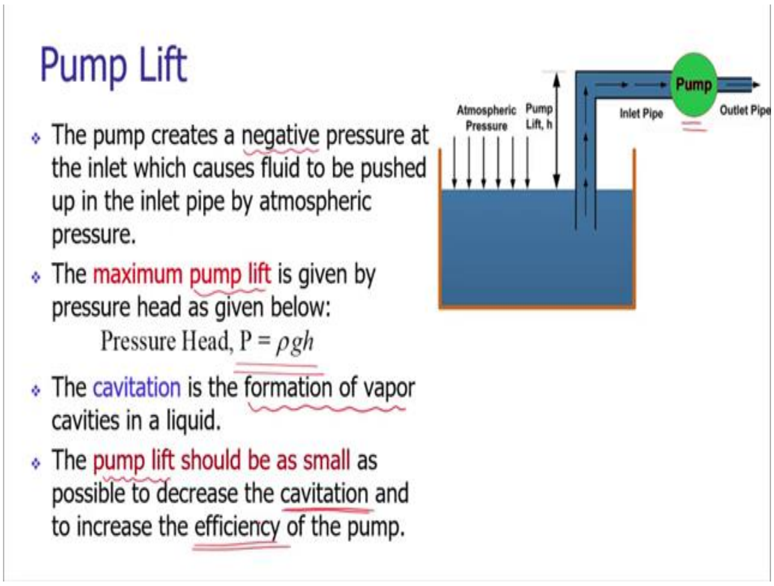
The crankshaft is rotated by using an electric motor as the crankshaft is rotating the crank is also rotating about the axis of the crankshaft. And, the rotary motion of the crank will be converted into reciprocating motion of the piston. As a piston comes down. This is called as the top dead center of the piston, cylinder arrangement and this is the bottom dead center.

As the piston is moving from TDC to BDC, the fluid will be drawn inside the cylinder area and during the returns stoke, the half stroke that is from BDC to TDC the pressure on the fluid would be increased. That pressurized fluid will pass through the outlet valve and it will be taken to the application through outlet port.

The piston cylinder arrangement inside the reciprocating pump is having a smaller volume that is why the quantity of the pressurized fluid would be less in a reciprocating pump.

We cannot have very bigger size or larger size of the reciprocating pump, the construction or the manufacturing of such a huge reciprocating pump is difficult. The advantage of the reciprocating pump is that the leakage is less and the systems are delivering constant volume of fluid in each cycle. By having a multiple number of such cycles, we can deliver in a precise amount of the fluid for our application.

(Refer Slide Time: 42:37)



As mentioned, in general the pumps are located or they may be located at a certain height from the fluid level inside the tank. In this situation, the pumps are creating the negative pressure, which is causing a vacuum and that vacuum is drawing the fluid from the fluid tank. That negative pressure which is lower than the atmospheric pressure will make the system will make the atmospheric pressure to push the fluid inside the inlet pipe and in this way we can have the start of the pump.

The maximum pump lift is generally given by the pressure head. That pressure head we can easily compute by the correlation:

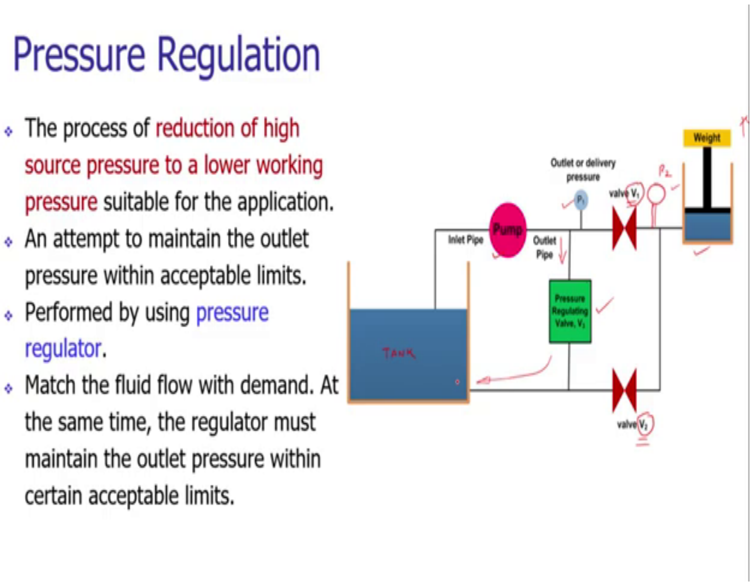
$$P = \rho g h$$

where,, ρ is the density of the fluid, g is the gravitational constant and h is the pump lift. When are we working with the pumps? Lot of heat energy is generated due to the high frequency operations particularly in the reciprocating pumps.

Since the volume is less, we have to run the pump at a very high rpm and when the high rpm pumps are working the friction would be more the thermal energy generated would be more temperatures are very high. These high temperatures are generating the vapors, this high temperatures are converting the liquid into it is vapor form. That process is called as the cavitation process.

And, this cavitation is leading the problem. It is creating the problem, it may also have the failure of the system. To have the lower problems inside the systems, it is recommended to have the lower pump lift, and that will lead to lower cavitation problems and enhancement in the efficiency of the pump.

(Refer Slide Time: 44:52)



In applications of the hydraulic system, many a times we need to have the holding of the weight for example the hydraulic clamps. The hydraulic clamps the hydraulic clamps the continuous pressurized fluid is to be applied, but that continuous application is leading to the increase in the pressure of the system, the pressure may be more than the operating pressure of the system.

For that purpose, we have to regulate the pressure inside the systems. Let us take an example, which is there on our screen. There is a system to lift the weight and it is having the tank, there is a pump and the piston cylinder arrangement.

There are two pressure gauges P 1 and P 2. The pump is drawing the fluid from the tank and it is pumping inside the piston cylinder arrangement. So, the valve V 1 and valve V 2 are controlling the flow of the pressurized fluid inside the system. The pressure gauge P 1 and P 2 are monitoring the pressure inside the system. Pressure gauge P 1 is monitoring the pressure at the outlet of the pump and the pressure gauge P 2 is monitoring the system at the load.

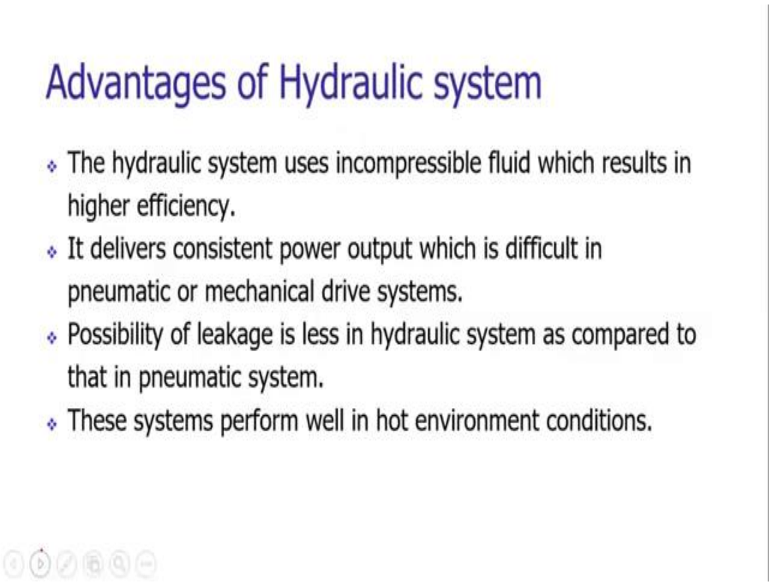
We are having two control valves V 1 and V 2. If, we operate valve V 1 and if we if we close valve V 2, the pressurized fluid is applied inside the piston cylinder arrangement and we can have the lifting of the weight. If, we close valve V 1 and the valve V 2 is open then we can have the lowering of the weight.

Let us consider valve V 1 and V 2 both are closed. And, the pump is the motor is on the pump is also on there is a continuous flow of pressurized fluid inside the system. This continuous flow is increasing the pressure inside the system. And, to regulate that pressure to reduce that high pressure to the working pressure, we are using the pressure regulating valve.

The pressure the pressure regulating valve is non-return type. It is operating; it is allowing the fluid that to flow in only one direction, but it will open at certain threshold value. And, that threshold value is set by the operator can be set by the operating person, when valve V 1 and V 2 are closed and the pressure inside the system is very high.

In that case the valve V 3 will open and the excess fluid will spill through this valve V 3 and it will be get back to the tank. In this way, we can safeguard the system by using a pressure regulating valve.

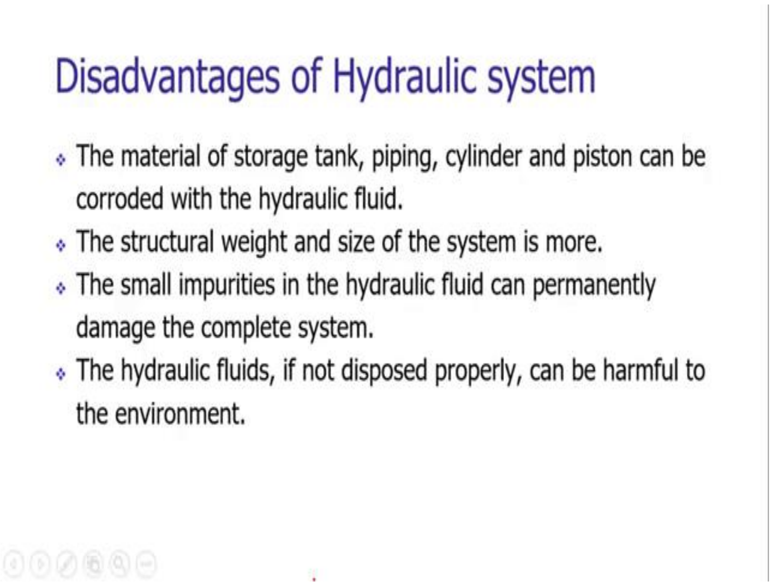
(Refer Slide Time: 48:30)



Hydraulic systems offer us a very good advantages the hydraulic systems are having higher efficiencies we are using incompressible fluid, that is resulting in a very good efficiency. The hydraulic systems are delivering consistent power, which is difficulty in the other prime movers such as pneumatics and mechanical drive systems.

The possibility of leakage in hydraulic systems is less in comparison with the pneumatic systems. And, the important advantage is that in hot conditions, when the temperatures are high, in that conditions as well hydraulic systems perform well in comparison with the other system that is pneumatic.

(Refer Slide Time: 49:31)



There are certain limitations to the hydraulic system as well the hydraulic systems are quite bulky, they involve, they comprise of many elements such as tanks, piping's, cylinder, piston and these elements are in contact with the hydraulic fluid. There may be chances of having corrosion of the hydraulic fluid, there may be having corrosion of all these elements. We have to protect this elements we have to have the regular maintenance of these mechanical elements.

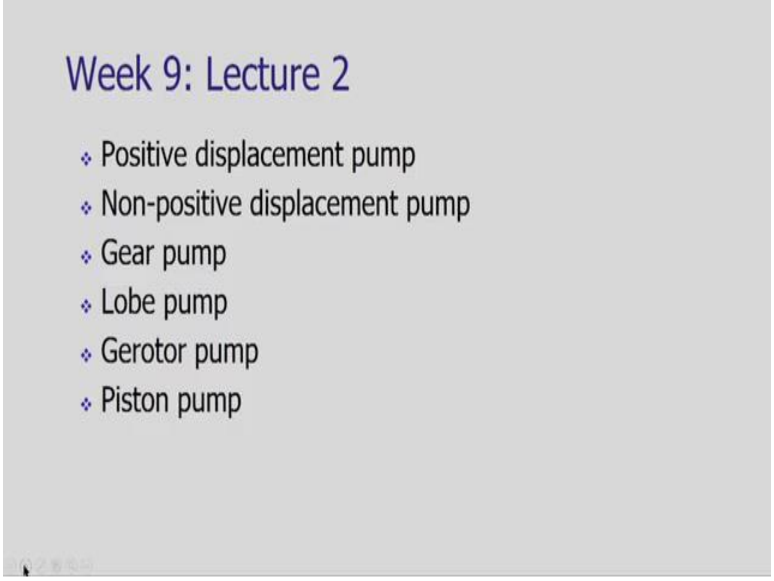
As number of elements are more, the size of the hydraulic system is also quite high these systems are bulky. In case there are certain impurities although they are in small quantities that made permanently affect the performance of the system. The hydraulic fluids which are the integral part of the hydraulic systems, if we do not dispose them properly that may lead to the environment hazards.

We have to take care about the disposal proper disposal of the hydraulic fluids. This is a limitation because we have to invest the time energy and money for the proper disposal of the hydraulic fluids. Well let me summarize the lecture 1, we started hydraulic systems in this week.

In the first lecture of week 9, we studied the fundamental concepts of the hydraulic system. The hydraulic system worked on Pascal's law, we have seen the definition of the Pascal's law. And, it is application how it is related to the hydraulic systems? After that, we studied various elements and the construction of elements of the hydraulic system.

There are certain applications which are very useful in automation industry that we have seen, later we had a discussion on the advantages and limitations of the hydraulic system. At the end we had a look at the classification of hydraulic systems.

(Refer Slide Time: 52:02)



In lecture 2 of week 9, we will study various types of pumps the positive displacement pump and non-positive displacement pump. A variety of pumps are being utilized in manufacturing industry which are the reciprocating pumps, gear pump, lobe pump, gerotor pump and many more. We will look at the important types of pumps which are useful in the industry.