Principle of Hydraulic Machines and System Design

Dr. Pranab K. Mondal
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture – 01
Introduction to hydraulic machines: Classifications and operational principles

I will discuss about Principle of Hydraulic Machines and System Design.

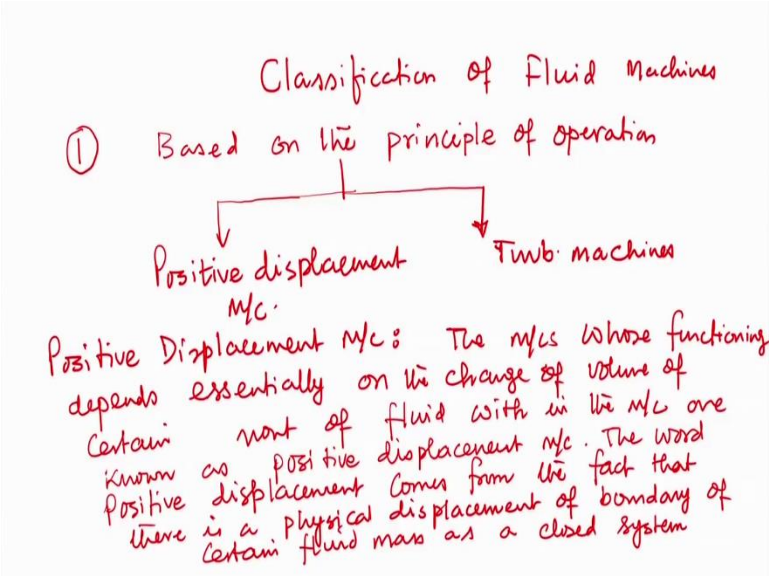
(Refer Slide Time: 00:37)

Week-wise Course Plan

Week	Lectures	Topics
1	L1	Introduction to hydraulic machines: classifications and operational principles
	L2	Euler equation for turbomachines: net head developed by the pump/turbines
2	L3	Velocity triangles of pumps, effect of inlet swirl on velocity triangles
	L4	Pump casing, efficiencies, problems
	L5	H-Q curve, system resistance curve
3	L6	Stodola sleep model: problems
	L7	NPSH: cavitation, effect of swirl on the cavitation
	L8	Radial flow pump testing
4	L9	Degrees of reaction: velocity triangle
	L10	Radial equilibrium for axial flow machines

Here, I briefly lecture wise schedule of the course content. First lecture, I will discuss about, Introduction to hydraulic machines, Classifications and operational principles and there are other lectures, where I will discuss different, you know parts of these course. The first lecture, I will talk about hydraulic machines classifications and operational principle. So, before I discuss about hydraulic machines, first I will discuss about the, classifications of fluid machines.

(Refer Slide Time: 01:10)



So, hydraulic machine is which falls under the fluid machines, when working fluid is essentially water. So, let me first discuss about the classification of fluid machines. There are different, you know issues by which I can classify fluid machines; first one is essentially based on the principle of operation.

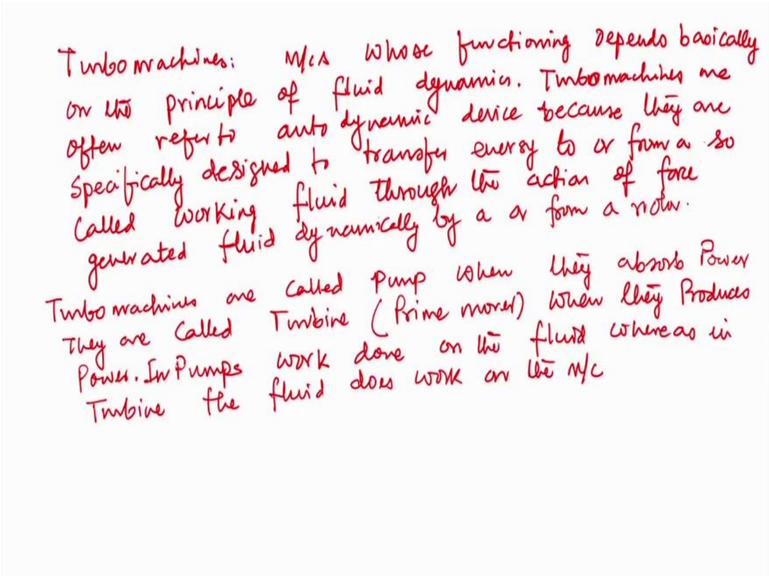
we can classify fluid machines into two different categories, first one is positive displacement machine, positive displacement machines and second is turbo machines, second is turbo machines. So, based on the principle of operation, we can classify fluid machines into two categories; one is positive displacement machine other is turbo machines.

So, what is positive displacement machine? What are positive displacement machines? The machine whose functioning I am writing, the machine whose functioning depends essentially on the change of volume of certain amount of fluid, within the machine, within the machine are the machines whose functioning depends essence on the change of volume of certain amount of fluid, within the machine are known as are positive displacement machines.

So, the machines whose functioning depends upon the change of volume of certain amount of fluid in the machine, those machines are known as positive displacement machine. The word positive displacement comes from the fact that comes from the fact that there is a physical displacement that there is a physical displacement of boundary of certain fluid mass of certain fluid mass as a closed system, as a closed system.

So, the word positive displacement comes from the fact that there is a physical displacement of the boundary of certain amount of fluid mass as a closed system ok.

(Refer Slide Time: 05:47)



The next is, turbo machines, the next is turbo machines right. So, turbo machines are the machines whose functioning depends, whose functioning depends basically on the, basically on the principle of fluid dynamics on the principle of fluid dynamics.

So, turbo machines are not be positive displacement machine, turbo machines are machine whose functioning depends basically on the principle of fluid dynamics right. Turbo machines are very often whether often referred to auto dynamic device, auto dynamic device, because they are specifically designed, specifically designed to transfer energy, to transfer energy to or from a so, called working fluid,

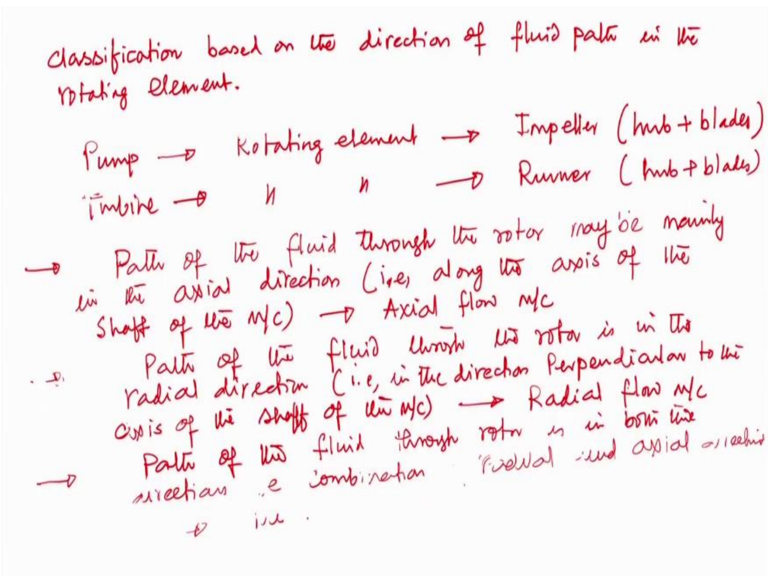
so called working fluid, working fluid through the action of force generated fluid dynamically by a or from a rotor. So, I am telling turbo machines are machines, whose functioning depends basically on the principle of fluid dynamics. Turbo machines are often referred to auto dynamic machine, because they are specifically designed to transfer energy to or from a so-called working fluid through the action of force generated fluid dynamically by a or from a rotor. This is; so, whatever we have discussed that fluid machines can be classified based on the principle of operation that is what we discussed till now. Now, this turbo machines are called pump, are called pump when they absorb power.

So, turbo machines are called pump, when they absorb power and they are called, they are called turbine. So, pump is a turbo machines when, because pump is a kind of turbo machines, which absorb power from the working fluid through the action of force generated fluid dynamically and turbo machines are called turbine or sometimes known as prime mover, when they produces power, when they produces power.

So, when turbo machines observe power, they are class of turbo machines I mean these are, they are known as pump. Turbo machines are called turbine or prime mover, when they produce power right. So, from this we can say that in pumps work done on the fluid; whereas, in turbine the fluid does work, the fluid does work on the machine.

So, we are calling turbo machines are pumps, when they absorb the power and they are called turbine, when they produce power. From this we can and say that in pumps work, in pumps work done on the fluid; whereas, in case of a turbine, fluid does work on the machines. Now, there are whenever we are calling at pump or turbine, there are two important rotating elements, we will discuss by today, in a later, time. So, next is we can classify fluid machines again; classification.

(Refer Slide Time: 11:54)



So, till now we have discussed about the classification of fluid machines in general, as I said that hydraulic machines are class of fluid machines and working fluid is water. Now, this fluid machine can be classified based on the direction of fluid path in the rotating element, based on the direction of fluid path in the rotating element, in the rotating element. Before I elaborate this aspect, let us discuss about rotating elements. In case of a pump, this rotating element, the rotating element for a pump which is known as impeller, which is known as impeller essentially, impeller is hub plus blades. So, the rotating element for the pump is the impeller, which is essentially hub plus blades. Similarly, the rotating element for the turbine, for the turbine rotating element is known as runner and again this is hub plus blades.

So, hub plus blades is known as runner for a turbine and the same thing hub plus blades, which is known as impeller for the pump. So, now, when you are going to discuss about the classification based on the direction of fluid path in the rotating element, we can again classify into two category, first one is the path of the fluid, path of the fluid through the rotor, through the rotor or rotating element, whatever telling through the rotating element or rotor

May be, mainly in the axial direction So, path of the fluid through the rotating element or through the rotor, maybe mainly in the axial direction, that is along the axis of the shaft of the machine.

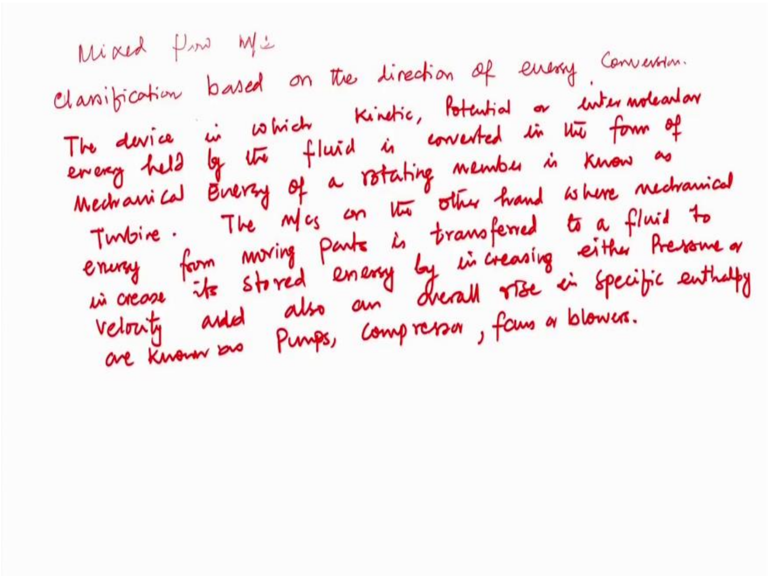
So, if the path of the fluid through the rotor or rotating element is mainly in the direction in axial direction that is along the axis of the shaft of the machine, then these are known as axial flow machines, it may be a pump, it may be a turbine. So, this is known as axial flow machine. So, axial flow machines that mean when path of the fluid element is mainly in the axial direction that is, that in the direction parallel to the axis of the shaft of the machine, these axial flow machines. Or there may be a case, when path of the fluid through the rotor.

So, when fluid is within the rotating element or rotor then if the path of the fluid is or rather through the rotor is in the radial direction, is in the radial direction that is in the direction, perpendicular to the axis of the shaft of the machine then this machines are known as radial flow machines, radial flow machines.

We call radial flow pumps or the turbine, may be radial flow. So, when path of the fluid element or path of the fluid through the rotating element is mainly in the radial direction that is in the direction which is perpendicular to the shaft of the machines, then these are known as radial flow machines. Or there may be a case that last one, there may be a case when path of the fluid element or path of the fluid path, of the fluid is path of the fluid through the rotor is in both the direction.

When path of the fluid through the rotor is in both the directions, that is combination of, that is combination of radial and axial direction. So, when path of the fluid in the rotating element is in the, is in both the direction; that means, combination of both the accelerated radial direction, then these machines are known as mixed flow machines.

(Refer Slide Time: 19:14)



Then the machines are known as mixed flow machines right, either mixed flow pump. So, we have discussed about the classifications based on the direction of fluid in the rotating element. The rotating element is known as impeller in case of a pump, which is essentially the hub plus blades, this rotating element is known as runner, in case of a turbine this is again hub plus blades. Finally, we can classify fluid machines based on the direction of energy conversions. So, last, we will discuss about classification based on the direction of energy conversions. This is very important, classifications based on the direction of energy conversion right.

So, this is the last classifications. So, first we have discussed about the classification based on the principle of operation. There we have seen that there is a positive displacement machines and turbo machines. Turbo machines are called pump, when they absorb power and they are called turbine, when they produce power, then we have discussed about the classification based on the direction of fluid, in the rotating element. There may be direction of fluid in the axial direction, that is in the direction parallel to the axis of the shaft of the machine in case of a axial flow machines or the direction of fluid in the rotating element may be in the radial direction, that is in the direction perpendicular to the shaft of the axis of the machine, then perpendicular to the axis of the machines.

This is not the radial flow machines or there might be a case when fluid path in the rotating element is, in the both directions that is the combination of radial and axial direction and that is known as axial flow machines. Finally, we will discuss about the classification based on the direction of energy conversions. So, the classification based on the direction of energy conversion. So, we can classify again.

So, the device;in which or machine we can say in which kinetic, potential or inter molecular energy held by the fluid, by the fluid is converted in the form of mechanical energy of a rotating member is known as turbine is known as turbine.

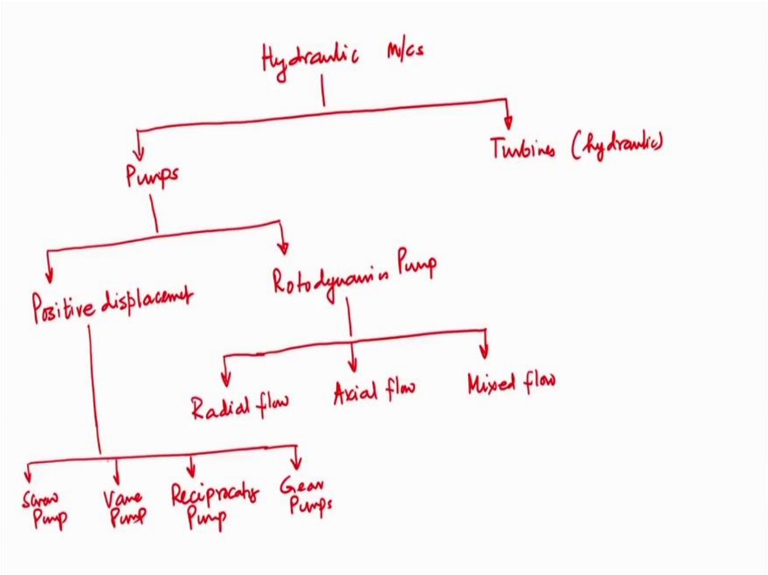
So, we can classify based on the direction of energy conversion, the first one, the device in which kinetic, potential or intermolecular energy held by the fluid is converted in the form of mechanical energy in a rotating member is known as turbine right. The machine on the other hand, the machine on the other hand where mechanical energy, where mechanical energy from moving parts is transferred to a fluid to increase its store energy, to increase its stored energy by increasing either it is pressure or velocity by increasing, either it is pressure or velocity and also an overall rise in specific enthalpy are the machines.

On the other hand, where mechanical energy from moving parts is transferred to a fluid to increase, it stored energy by increasing either pressure or velocity and an overall rise in enthalpy are known as pumps, compressors, fans or blowers.

So, the last classification that is based on the direction of energy conversion, first of all the device in which kinetic potential or inter, intermolecular energy help by the fluid is converted in the form of mechanical energy of a rotating member is known as turbine. On the other hand the machines where mechanical energy from moving parts is transferred to fluid, to a fluid, to increase its stored energy by increasing either it's pressure or velocity and also on overall rise in enthalpy are known as pumps, compressor fans and blowers.

So, this is all about the classification of the fluid machines. Since, in this course I will focus on the hydraulic machines. So, now, I will go to the, classification of hydraulic machines. So, far we have discussed that they are might be a hydro, hydraulic machines, again is a class of fluid machines while working fluid is water. So, we can hydraulic machine, we can divide into again two, categories.

(Refer Slide Time: 27:11)



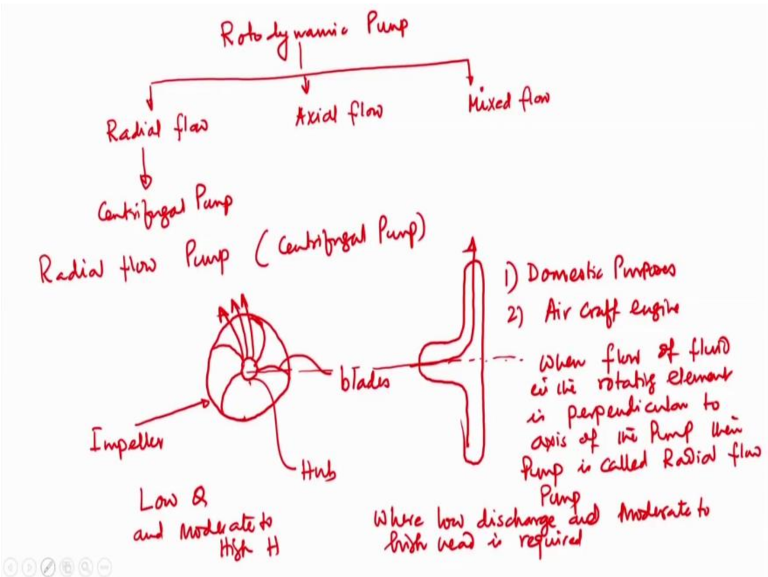
So, hydraulic machines, hydraulic machines one is as I said that there be again positive displacement pump, it may be a positive displacement pump or I can say that there may be pumps, hydraulic machines pumps or we have a turbine, hydraulic turbine.

So, hydraulic machines we are classified, we are dividing into two parts; two categories one is pump, another one is turbine, because we have seen that in case of a pumps, it is hydraulic machine is a class of fluid machines are working fluid is water, in case of a pump it absorb energy, but hydraulic turbine it produces energy.

So, pump again we can classify into two different categories, one is roto dynamic pump, roto dynamic pump and other one is positive displacement pump. So, as I said that positive displacement pump, there is a physical displacement of the boundary of certain fluid mass as a closed system. So, positive displacement pumps and roto dynamic pumps; roto dynamic pumps again further classified that I have discussed, that based on the direction of fluid path, it may be a radial flow, it may be a radial flow pump, it maybe axial flow pump and it may be a mixed flow pump. So, and turbine again, it may be a radial flow, hydraulic turbine, it may be a axial flow, hydraulic turbine. So, this is the broad classification of hydraulic machines, pumps and turbo hydraulic pump, pumps and turbo hydraulic turbines; pumps can be classified into two categories, positive displacement pump.

There are so many positive displacement pumps; screw pump, then we have gear pumps, vane pump, we have reciprocating pump, all reciprocating pump or we have gear pump, all these are positive displacement type, while we have a roto dynamic pump. Again, roto dynamic pump can be sub classified into three categories, radial flow machines, radial flow pump, axial flow pump and mixed flow pump ok. So, now, we will discuss different pumps one by one.

(Refer Slide Time: 30:22)



So, first we will discuss about the roto dynamic pump. Roto dynamic pump, as I said that this roto dynamic pump can be sub classified into three categories, one is radial flow, another is axial flow and last one is mixed flow type. So, roto dynamic pump can be sub classified into three categories, radial flow pump, axial flow pump and mixed flow pump as I have discussed that in case of a radial flow pump, the direction of fluid in the rotating element is in the mainly, in the radial direction that is in the direction perpendicular to the axis of the machine. In case of axial flow machines, the direction of the fluid in the rotating element is only in the axial direction, that is in the direction parallel to the axis of the shaft of the machine and in the mixed flow machine, the fluid direction maybe in both, parallel and both axial and radial. So, in case of a radial flow machines, sometimes we call the radial flow pump. So, radial flow pump sometimes is known as centrifugal pump, is a commercial name, centrifugal pump. We in most of the undergraduate textbook, it is written centrifugal pump. Centrifugal pump is the commercial name of the radial flow pump, because the radial flow pump by virtue of centrifugal action, you know we develop head of the water.

So, but it is radial flow machines, because the direction of fluid in the rotating element is only in the radial direction, axial flow machine and mixed flow machines. So, in case of if I draw, you know a centrifugal pump, so, we will discuss first about the radial flow pump, radial flow pump or it is known as centrifugal pump also, I should suggest calling it a radial flow machines, because if only, because of the presence of centrifugal action, if we call it centrifugal pump I0n a mixed flow pump there is again, centrifugal action is present. So, again we have to call it centrifugal pump. So, it is always better to call it radial flow machines, radial flow pump.

So, if I draw a schematic of a radial flow pump, so we are drawing a pump, impeller so small. This is known as hub, this is known as hub and there are many other, many blades. So, these are blades.

Since this hub plus blade, as I said this hub plus blades, this is known as impeller, which is rotating element of pumps. It may be a radial flow, axial flow or mixed flow. So, this is radial flow and the direction of fluid element, this is the direction of axis is perpendicular to this board and fluid is going outwards, so, which is in the perpendicular to the direction of the axis of the shaft. So, this is radial flow machines, if I take a cross section view, it, it looks like this. So, if I take, if I draw then; so, fluid moves in this direction.

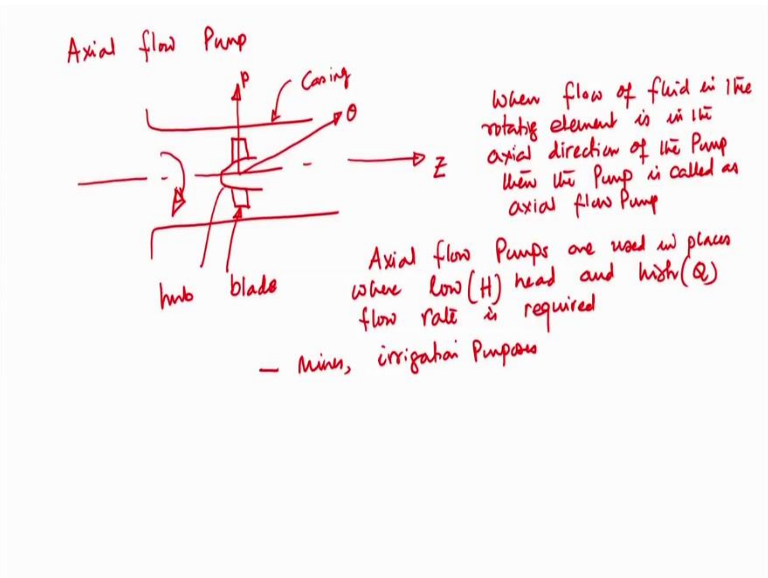
This is the direct, this is the axis of the shaft of the machines, while the fluid is in the perpendicular direction. So, this is radial flow machines and this radial flow pumps I mean is very often used in domestic purposes, the applications are in domestic purposes eases for lifting water in multi storage building or sometimes it is used, you know in aircraft engine and aircraft engine, it is also used, domestic purpose is mainly used for domestic purposes or sometimes used in aircraft engine.

So, special feature of this pump is, when flow of fluid in the rotating element is perpendicular to the axis of the pump, perpendicular to the axis of the pump then pump is no called, then pump is called radial flow pump. So, we should remember when fluid, flow of fluid in the rotating element is perpendicular to the axis of the pump then it is called, the pump is called radial flow pump.

It is used mainly in the domestic purposes or sometimes it is also used in aircraft engine. It is used where very important, where you know low discharge relatively, low discharge and, it is used when relatively low discharge and high head rather moderate to high head, moderate to high head is required. So, it is used in places where we require relatively low discharge and moderate to high head then we generally go for installation of radial flow pump. The radial flow pump when flow of the fluid in the rotating element is in the perpendicular direction of the axis of the pump, then we call it radial flow pump.

This is used in places where we require low head and moderate to high discharge that is low Q and moderate to high discharge and moderate to high H. So, when we require low discharge, low Q flow rate and moderate to high head then we go for installation of radial flow pump. It is used mainly in the domestic purposes, sometimes it is used in the aircraft engine.

(Refer Slide Time: 38:32)



.

Next, we will go for the axial flow pump, axial flow pump. So, again I will draw schematic. So, this is hub plus blades which is known as imp impeller. So, these are pump casings, this is casing, which surrounds the impeller, this is known as blade and this is hub, so, hub plus blades which is impeller, which is surrounded by a casing. Now, we have a three directions Z, R and θ.

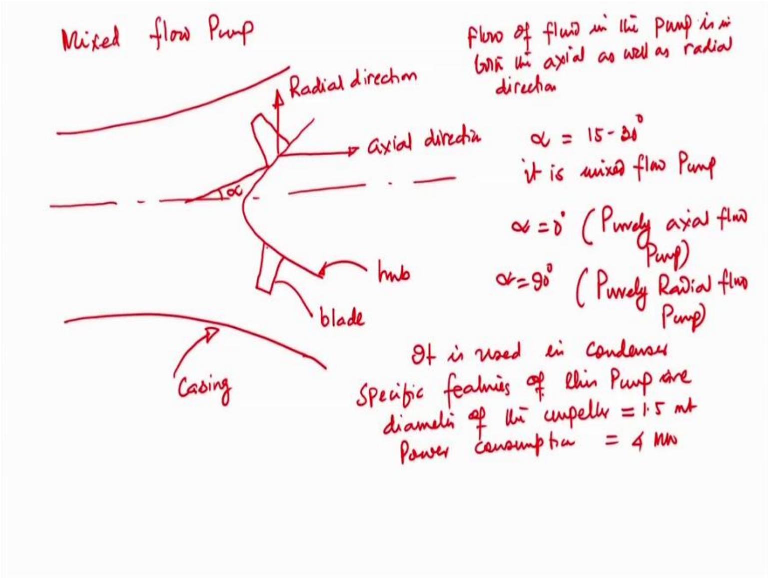
So, R θ directions pump is rotating in these directions right. So, when flow up, the pump special feature of the axial flow pump as I told you already that I have already discussed about the direction or classification of fluid machine based on the direction of fluid. So, we can call it pump, when it observe power similarly, for the axial flow pump, we can call it axial flow pump, when flow of the, when flow of the fluid or flow of flow of fluid, flow of fluid, in the rotating element is in the axial direction, axial direction of the machines or pump of the pump.

What is axial direction? That is in the direction parallel to the axis of the machines or pump, then when flow of fluid in the rotating element is in the axial direction of the pump, then the pump is called as then the pump is called as axial flow pump, right. So, here mainly, flow direction, flow of the pump that the fluid in the rotating element is in the axial direction of the machines or pump and it is axial flow pump.

Axial flow pumps are used very important; axial flow pumps, axial flow pumps are used in places where you require low head, but high discharge used in places where low head, low head and high discharge or high flow rate, high flow rate is required. So, axial flow pumps are used in places, where we required low head, but you require very high discharge. There are several places mostly in mines, irrigation purpose, irrigation purpose, irrigation purposes and coal mines. So, the application of axial flow machines, axial flow pumps are in the coal mines or and in the irrigation purposes, because in that cases we required high discharge, but head is low, we required low head, we do not require very high head.

So, this axial flow pump finds applications in, those areas. Last, we will discuss about the mixed flow pump, mixed flow pump.

(Refer Slide Time: 43:05)



So, this is again pump axis, this is blade, this is bud, this is pump casings. Now, here, the blade or the hub makes an angle alpha with the axis of the machine. So, this is angle alpha.

So, there are two direction of, one is axial direction, another is radial direction. So, here, alpha for the mixed flow pump is typically from 15 to 30 degree, when alpha is 15 to 30 degree, it is mixed flow pump. It is mixed flow pump and flow of fluid in the pump is both is in both the axial as well as radial direction.

So, in case of mixed flow pump as we have discussed, the flow of the fluid in the rotating element is, is in both the direction that is both in the axial as well as radial direction. Here, we have I have drawn a schematic had alpha is the angle, made by the blade with axis of the machines with axis of the pump; alpha typically varies from 15 to 30 degree for when it is 15 to 30 degree typically varies from 15 to 30 degree for mixed flow pump. Note that if alpha becomes 0, that is it is purely axial flow machines.

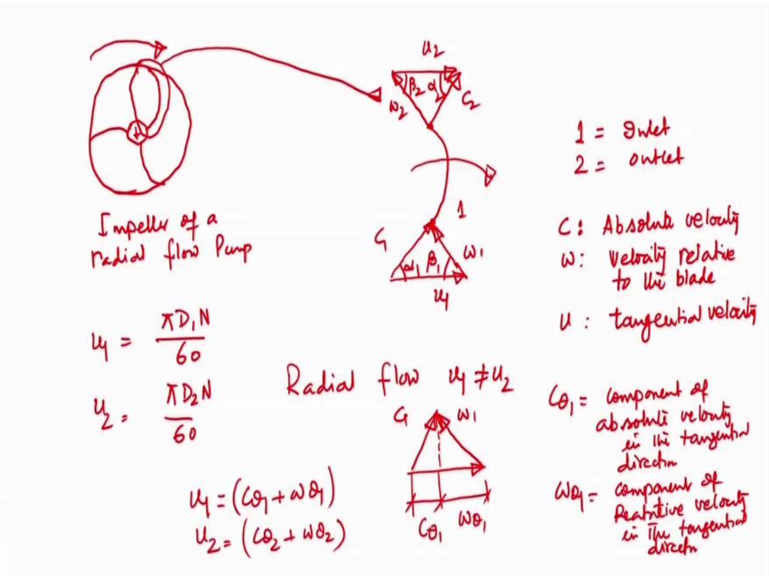
So, when $\alpha = 0$ then it is purely axial flow machines, purely axial flow machines or axial flow pump that is why I have drawn this radial and axial direction and when alpha is equal to 90 degree then this is purely radial flow machine, purely radial flow machines or radial flow pump. So, α depending upon the magnitude of α, if α typically varies from 15 to 30 degree for mixed flow pump, it becomes 0, when it becomes 0, then it is purely axial flow machines and when it becomes 90 degree, it is purely radial flow machines.

Now, as I said you that in case of a mixed flow pump, there two components. So, there are two components of flow; one is in the radial direction, another is in the axial directions and that is why it is called mixed flow pump and it is used in condenser and cooling water duties, it is used this mixed flow pump, it is used in condenser for cooling water duty sperm, the specific feature of this pump is, specific feature of this pump is it, diameter of the impeller diameter of the impeller roughly 1.5 meter. It is big pump and power consumption is of the order of 4 megawatt.

So, it is used in condenser cooling water duties pump. It has two components of flow; one is in the radial direction another is in the axial direction. That is why we call it axial flow pump. We have done a schematic of the blade's impeller; I mean blades hub. So, this alpha typically, varies from 15 to 30 degree for the mixed flow pump. The specific feature of this pump is rather than specific features of this pump are director of the impeller is 1.5 meter and power consumption is 4 megawatts.

So, this is all about the classification roto dynamic pump and positive displacement pump as I said that again, this is a machine, in which there is a physical displacement of the boundary of certain amount of fluid mass, as a close system. So, that is why the name positive displacement comes. Now, we will briefly discuss about the velocity triangles of a radial flow pump.

(Refer Slide Time: 48:55)



So, if I draw impeller that is hub as well as blade of and suppose, pump is impeller is rotating in the clockwise direction.

So, this is an impeller of a radial flow pump, this is an impeller of a radial flow pump. We will discuss velocity triangles for all the pumps axial flow pump as well as a mixed flow pump. So, before I go to discuss about the Euler's equation of a machines that is which gives us an idea about the head generated by the pump, Euler equation of pump turbines. So, now, I will briefly discuss about the velocity angles.

So, this is an impeller of a radial flow pump. As I said that here, the direction of fluid is in the radial, is radially outward, that is perpendicular to the axis of the machines. Now, if I take out a particular blade, these are blades and small one is a hub. So, hub plus blade is a impeller and the impeller is rotating in the clockwise direction. So, if I take out a particular blade and if I draw a zoomed in view of the particular blade, so, let us say this is 1 and this is 2.

So, 1 is the inlet and 2 is the outlet. So, suffixes 1 and 2 are used to denote inlet and outlet of the pump. So, 1 is the inlet and 2 is the outlet of the pump and this is the blade and this is rotating in the clockwise direction. So, there are three components of velocity, I mean at the inlet and outlet, say if I draw the velocity angles at the inlet. So, the velocity triangle at the inlet, so, this is 1. So, this is; so, this is the inlet.

If I draw the velocity triangle at the inlet, so, this is the velocity component c_1, I am talking c_1, this is the velocity component, I am calling it w_1 and this is u_1, where c is the absolute velocity, absolute velocity of water, w is the velocity of water relative to the blade; velocity relative to the blade, relative to the blade or when and u is the tangential velocity.

So, there are three different components of velocity; one is absolute velocity of water c, w is the velocity relative to the blade and U is the tangential velocity. Now, suffix 1 is used to denote the velocities at the inlet. Similarly, I can draw the velocity triangle at the outlet that is u_2, this is c_2 and this is w_2, c_2 is the absolute velocity at the outlet w 2 is the velocity relative velocity at the outlet and u_2 is the tangential velocity at the outlet.

$$U_1 = \frac{\pi D_1 N}{60}$$

$$U_2 = \frac{\pi D_2 N}{60}$$

where D 1 and D 2 at the diameter of the, inner diameter, outer diameter of the emperor impeller right. So, now, there are so many other issues. So, this alpha the velocity component c_1's, which makes an angle alpha with the absolute velocity sorry, of the tangential velocity α_1, this is $\beta 1$, this is $\beta 2$ and this is $\alpha 2$.

So, these are the separate different nomenclatures of angles at the inlet and outlet, we will discuss later. So, before I go to discuss about the Euler equation for pumps, Euler equations of pump turbine, Euler equation for pump and turbine, this is a primarily idea about the velocity triangles at the inlet and outlet on a pump. So, we have seen there are three components, one is the tangential velocity that is, because of the impeller is rotating at a certain RPM.

And at the inlet and outlet of the impeller, the diameter of the hub and diameter of the impeller are different. So, we are having $\frac{\pi D_1 N}{60}, \frac{\pi D_2 N}{60}$. Here, for a radial flow pump, for a radial flow pump $u_1 \neq u_2$, but we will see that for a axial flow pump, u_1 is equal to u_2, because these diameter D_1 and D_2 are the same and c 1 is the absolute velocity.

Now, if I take a particular say, if we take, if we draw the inlet velocity triangle separately, we will get like this. So, this is u_1, this is c_1, this is w_1 and component of absolute velocity in the tangential direction. This is known as $C_{\theta 1}$ and component of relative velocity in the tangential direction, I call it $W_{\theta 1}$. So, $C_{\theta 1}$, these are very important to discuss, when you will this, these are very important when I discuss about the Euler equation of turbine pump.

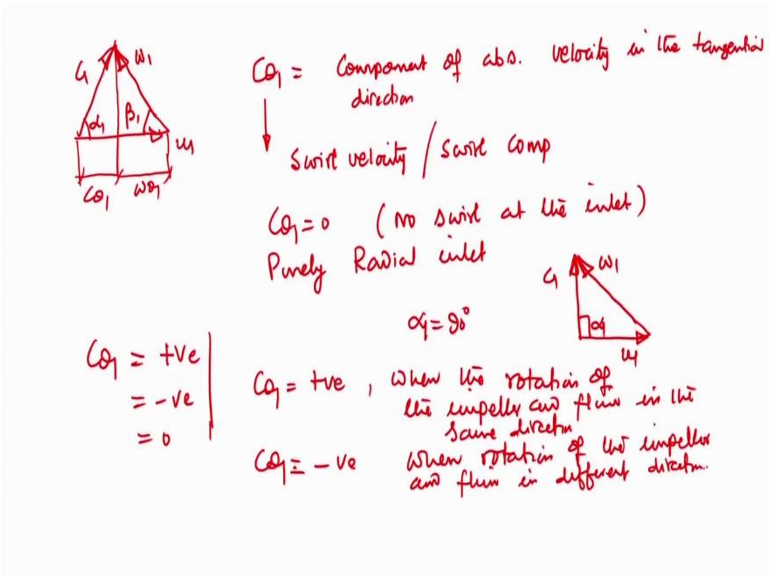
So, $C_{\theta 1}$ is the components of absolute velocity in the tangential direction, absolute velocity in the tangential direction. Similarly, $W_{\theta 1}$ is component of relative velocity in the tangential direction. So, we may similarly, in a hub $C_{\theta 2}$ and $W_{\theta 2}$ at the outlet. So, the component of absolute velocity in the tangential direction and component of relative velocity at the component of relative velocity in the tangential directions are $C_{\theta 1}, W_{\theta 1}$ at the inlet.

Similarly, we make it here, $C_{\theta 2}$ and $W_{\theta 2}$ at the outlet. Now, this $C_{\theta 1}$ is known as swirl velocity, the component of absolute velocity in the tangential direction, it is known as swirl component of velocity. For a there might be, case that is known as radial purely, radial inlet, where $C_{\theta 1}$ will be 0 that is no swirl at the inlet. So, this is I mean defined velocity triangles at the inlet and outlet.

So, from this inlet velocity triangle, what we can see that the tangential velocity at the inlet is the summation of $C_{\theta 1} + W_{\theta 1}$. That is component of absolute velocity in the tangential direction plus component of the relative velocity at the tangential direction is the tangential velocity at the inlet.

Similarly, we can have $u_2 = C_{\theta 2} + W_{\theta 2}$; that is component of absolute velocity at the, in the tangential direction plus component of relative velocity at the, in the tangential direction is the tangential velocity at the outlet. So, this is the inlet and outlet triangles, as I said that when again I am drawing the similar velocity triangle.

(Refer Slide Time: 57:45)



So, this is u_1, this is $C_{\theta 1}$ and this is $W_{\theta 1}$, this is w_2, w_1 and this is c_1, this is α_1 and this is $\beta 1$. Now, $C_{\theta 1}$ as I said you, this is component of absolute velocity, component of absolute velocity of water, in the tangential direction. So, component of absolute velocity in the tangential direction, which is known as swirl velocity component of swirl. So, this is swirl component or swirl velocity or it is swirl component.

So, component of absolute velocity in the tangential direction is swirl velocity or swirl component. So, component of absolute velocity in the tangential direction is the swirl velocity or swirl component. Now, if you do not have swirl; so, suppose when $C_{\theta 1}$ =0 that is no swirl at the inlet that is no swirl at the inlet, that is purely radial inlet, purely radial inlet, purely radial inlet pump, where $C_{\theta 1}$ = 0 that is no swirl component at the inlet. So, there the velocity comp, velocity triangles look like this, this is c_1, this is w_1.

Since u 1 is fixed, so, this is u 1, c 1 and this is w 1. So, this is α_1 = 90 degree that is purely radial inlet. Now, component of swirl, no swirl velocity. Now, the, we will see that when we discuss about Euler equation for pumps then the component of $C_{\theta 1}$ has a big role to play to, when we talk about a head developed by the pump. Now, c theta 1 may be positive or negative; c theta 1 may be positive or it may be negative, or it may be 0. So, when it is 0 that is α_1 = 90 degree, this purely radial inlet, no swirl component. Whether $C_{\theta 1}$ is positive or negative? That means, there is swirl. So, $C_{\theta 1}$ will be positive, when the rotation of the impeller and fluid in the same direction, when the rotation of the impeller and fluid in the same direction and $C_{\theta 1}$ will be negative, we will see that, negative component of swirl velocity may be helpful to the net head develop of the pump, but sometimes it may not be possible to have a negative component of swirl velocity, because it may leads to another problem as far as the pump operation is concerned.

So, when $C_{\theta 1}$ is positive; that means, when rotation of the impeller and fluid in the same direction, then it becomes positive swirl or sometimes it may have a negative swirl component velocity, when the rotation of the impeller, when rotation of the impeller and fluid in the different directions, in different direction.

So, today I have just done the inlet and outlet velocity triangles. We have discussed about different component of velocities and we have seen that this $C_{\theta 1}$ that is component of absolute velocity in the tangential direction maybe 0, may be positive, may be negative, A 0 or $C_{\theta 1}$, that is no swirl at the inlet, purely radial inlet, positive $C_{\theta 1}$ that is positive component of swirl velocity, when rotation of the impeller of fluid in the same direction.

But we may have a negative swirl that is when the rotation of the impeller and the fluid is in the different direction and negative c theta component play a big role, I mean when we need to develop a higher head from a pump. So, today we have discussed about if I summarize today, we have discussed about the classification of fluid machines broadly, without taking a special case of hydraulic machines.

We have classified fluid machines in different ways, that based on the principle of operation, there we have define turbo machines and positive displacement and we have seen that in case of a turbo machines, when the machine absorb power, they are basically pump when they produces power, they are basically hydraulic turbine.

We may define fluid machines in that, depending upon the direction of the fluid in the rotating element. It may be a radial flow, it may be a axial flow or it may be a mixed flow, when there, there are two components of flow direction, both in the axial and radial direction.

Also we have seen that the fluid machines can be classified based on the direction of energy transfer. I mean, it may be a pump compressor or blower, or it may be a turbine. So, and then we have taken a special case that is the pin hydraulic machines, which can be classified into pumps and turbines hydraulic turbine and pumps. Pumps can be sub classified into two categories, positive displacement pump and the roto dynamic pump. Positive displacement pump there are so many time, I mean screw pump, jet pump, gear pump, disc crew cutting pump and positive displacement pump are used, where you require a very low amount of discharge and very high head, where we have discussed that roto dynamic pump can be classified into three categories; radial flow, axial flow and mixed flow.

Radial flow pump flow direction or flow of the fluid in the rotating element or in the impeller is in the radial direction that is in the direction perpendicular to the axis of the machines and it is used mainly for domestic purposes and in aircraft engine, where we require a low to moderate you know, moderate to high head and low discharge. Axial flow machines, we have seen that when flow of the fluid in the pump is in the, is mainly in the axial direction and it is used mainly in the coal mines and irrigation purposes, where you required high discharge low head and mixed flow pump we have seen there are two components of, you know flow of the fluid, I mean both in the axial radial direction.

And we have seen that it the blade makes an angle, alpha with the axis of the impeller, alpha typically varies from 15 to 30 degree for the mixed flow pump and it has a specific feature, the diameter is very big, 1.5 meter and diameter of the impeller and it consumes a huge amount of power and it is used for the condense, in condenser for cooling duties, cooling water duties pump.

And then we have taken a radial flow pump we have tried to draw the, we have drawn the velocity triangles, both at the inlet and outlet, because this velocity triangles is very important to have an idea about the head develop by the pump itself.

So, we have seen there are three components of velocities both are the inlet and outlet, absolute velocity of water, velocity of water relative to a bin and there are tangential velocity.

Tangential velocity of the impeller at both at the inlet and the outlet are not same, because diameters are different and we have identified that we have decomposed the, you know absolute velocity in the tangential direction and radial velocity, you know relative velocity in the tangential direction and we have seen that the component of absolute velocity in the tangential direction, which is known as swirl velocity or swirl component. It may be a positive, it may be a negative or it may be a 0, 0 means that is, it has no swirl at the inlet that is purely radial inlet.

While positive or negative c theta that is positive and negative swirl velocity we can have, because depending upon the rotation of the imperial and fluid. So, whenever impeller and fluid are rotation of the, impeller and fluid are in the same direction then we may have positive $C_{\theta 1}$ or we may have a negative $C_{\theta 1}$, when they are rotating in the different direction.

We will see that the negative $C_{\theta 1}$ has, you know, you know play a big role, whenever we are talking about net, had developed by the pump, but by creating a negative swirl velocity at the inlet, we may develop fire head, it creates another problem as per as the pump operation is concerned, we will discuss in the next class.

Thank you.