Introduction to Fluid Mechanics and Fluid Engineering
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Lecture – 49
Introduction to Fluid Machines

Today, we will start with our discussion on fluid machines. This is not a full level course on fluid machines. So we will not go into all sorts of intricate details but our entire objective will be to look into the fundamental concepts that go behind the principles of operations of fluid machines. When we say fluid machines, what do we basically mean? Fluid machines are those types of devices which either extract energy from the fluid and do something or impart energy to the fluid. For example, let us say that you have pump.

What does the pump do? It basically inputs or energises the fluid with some sort of power or energy and with that energy, now maybe the fluid is lifted to some height or elevation. On the other hand, if you have a turbine, what does the turbine do? It basically takes some energy from the fluid and converts that into first mechanical form of energy and them to electrical form of energy.

So it basically, the fluid machine is basically either extracting the energy from the fluid or imparting the energy to the fluid. In that way, it may be either work producing device or a work absorbing device. Now when we typically deal with fluid machines, we have to keep in mind that the fluids which are being handled by the machines, may be of different types. They maybe compressible fluids, they might be fluids with negligible compressibility or so-called incompressible fluids.

In this particular course, we will be bothered mostly on fluid machines where the fluid being handled is an incompressible one and typically water only. So that is why, although we call it fluid machines but most of the discussions will be on hydraulic machines, that is machines which deal with water and we have to keep in mind that although we will be confined mostly to that, some of the basic principles that we develop are still applicable for different types of fluids which are being handled by other types of fluid machines.

Now we have mentioned about the work producing and work absorbing devices and these devices again may be classified in different ways. For example, say when we consider a pump which is like sort of which is imparting the energy to the fluid. Now with that energy, different purposes may be achieved. So when an energy is imparted to a fluid by that, it may be good enough to have a static lift, that is increase in elevation from a lower level to the higher level which the pump often does and usually it handles a liquid.

Now it may so happen that the purpose is not to increase the height but to change the pressure and say it is handling some compressible fluid, say air and say the similar type of device, it is energising the fluid but the whole purpose is to increase the pressure of the fluid and the fluid is a compressible one. In that case, it may be called as a compressor. So the basic scientific aspect may remain very, very analogous.

But depending on the purpose, we are now no more calling it a pump but we are calling it a compressor. The objective then is to increase the pressure and obviously the fluid that is being handled has to be a compressible one and it may so happen that the purpose is neither giving elevation nor giving or not imparting a rise in pressure but maybe just to create a flow or create or impart a kinetic energy to the fluid and then similar type of device may be called as a fan.

So we know that a fan or a blower, the purpose is to create a kinetic energy of the… The next point is whenever we talk about these types of devices, we may think of the basic hardware which is implementing the particular application that is either producing work or absorbing work and that hardware may have broadly 2 types.

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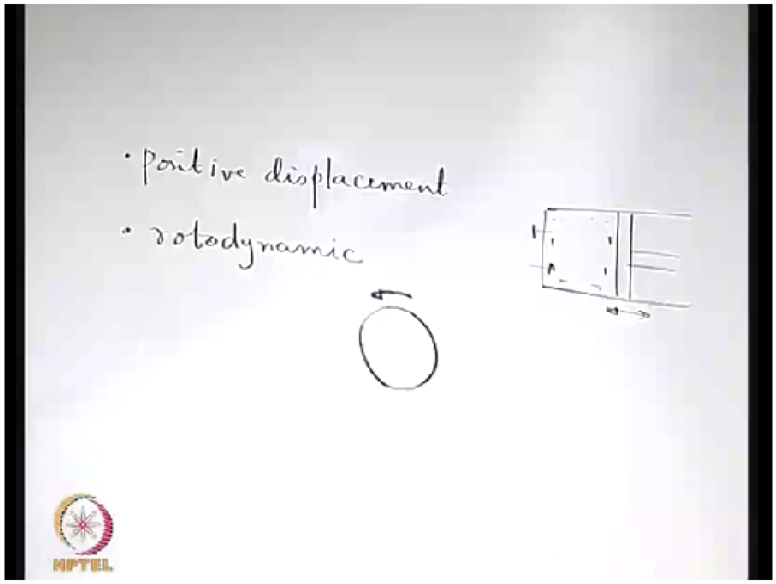

And based on that, one may have either a positive displacement type of fluid machine and the other type is a rotodynamic fluid machine. The positive displacement type of fluid machine, what it basically does? It relies on the change in volume of a fluid in a given confinement. We will give an example. Let us say that you have piston and a cylinder and say there is some compressible fluid which is being there, contained in the piston/cylinder arrangement.

Now as the piston reciprocates, there is a change in volume of the working fluid and accordingly, if it is a compressible one, there will be change in pressure and the fluid may flow in and out of this depending on the possibility of having certain valves associated with the cylinder, so the valves may open and close and accordingly fluid may flow in or out. So this is an example of a positive displacement device.

But this is not the only example but we have to keep in mind that the sole policy of this is to have a change in volume of the working fluid in a confinement. It need not always be a reciprocating type but there may also be a possibility of change in volume because of the flexibility of the device itself. A classical example is human heart. Human heart is such a type of pump which is also known as the diaphragm pump where basically has a flexible diaphragm.

And because of contraction and expansion of that, you have a change in volume of the working fluid which is there inside. So such devices are known as positive displacement devices. On the other hand, rotodynamic devices, from the name it is clear that it has something called a rotor and rotor is something which is basically a rotating part or a rotating device and when the rotor rotates, there is something which happens because of which there is either energy imparted to the fluid or energy is taken away from the fluid.

So rotodynamic device will be based on the working principle of the rotation of something called as a rotor, I mean the rotor may have different names for different devices. For example, for a centrifugal pump which we will come across soon, it is known as an impeller and for a Francis turbine which is just an opposite type of a device, then it is known as a runner. So you may have different types, just different technical names but it is basically that you have some rotating part.

What does the rotating part do or what does it achieve? You have a fluid, the fluid interacts with the rotating part and there is a change in direction of the fluid as it is moving across the rotating part. So there is a change of linear momentum of the fluid and the change in linear momentum will have or the rate of change in linear momentum will have a moment with respect to the axis of the rotor.

So there will be also a rate of change of angular momentum and that will mean that there is a net torque with respect to the axis of the rotor and in that way, either energy is imparted to the rotor or if the rotor is rotating that already by some energising device, then that rotational energy is imparted to the fluid. So basically the rotodynamic devices will work on the principle of the angular momentum change.

And we will see that how one may utilise that principle to either develop some power or extract some power from the fluid. Now when we talk about these 2 types of devices, it is not a bad idea to just have a review on their relative advantages and disadvantages. So when you talk about say the positive displacement devices, one of the important complexities, it need not necessarily be a advantages, but it is a complexity that the flow in a positive displacement device is inherently unstable.

It cannot be a steady flow, whereas in a rotodynamic device, although technically there will always be some unsteadiness but the unsteadiness is not that significant. So it may be broadly designed or analysed by considering a steady flow without too much of an error but the positive displacement device fundamentally, it is strongly unsteady. The second thing is that if you look into a piston/cylinder type of a device, always there will be a gap between the piston and the cylinder and the reason is that you want to avoid solid to solid contact.

So what is typically done is in the gap between the piston and the cylinder, some lubricating oil that is being kept. Now it prevents the metal to metal contact as an example but sometimes it creates problems because the fluid if it contains particulates, then those particulates may get trapped in the gap between the piston and the cylinder and then it will start malfunctioning. So if there are particles in the fluid and it is possible that the device is handling some granular fluid and then such granules are present, it may clog this type of a passage.

The third thing which is a very interesting thing is that, what happens let us say that you close these 2 valves and you pressurise the fluid inside. Say the piston is going moving inside, these valves are closed. So it will go on but that means you are imparting the energy to the fluid but fluid is not going out. So what will happen? It will get pressurised, pressure will build up and there may be a state when the pressure rise is so high that there may be a burst of the space which is, I mean, the cylinder may burst because of an excessive high pressure.

On the other hand, let us say that you have rotodynamic device and in between the rotors we will see examples where you have some blades and in between the blades of the device because blades create a change in direction of the fluid, so in between the blades, say there are fluids and you are allowing it to rotate but you are not allowing the fluid to leave. That is there is a valve which is closed in the pipeline so that the fluid which is coming out of the device, it cannot leave.

Say you have pump; the rotor of the pump is rotating but the delivery valve is closed. So then what will happen? Then, see in this case, what may happen is something which is very, very catastrophic. In this case, it will merely churn the fluid. It will just go on rotating the fluid but it will not create such an abnormal rise in pressure and so in a way that is a much safer operation.

On the top of that, positive displacement devices for a given purpose if you have these 2 types of devices, positive displacement types of devices are much more bulky and rotodynamic devices are relatively more compact and that is why for most of the applications wherever possible, we go for rotodynamic device. It does not mean that the positive displacement devices are not used.

They are very much used for some specialised applications in the industry but in this particular course, we will focus or concentrate more on the rotodynamic devices. Now what we will do is, we will look into some visuals first to understand that what are the basic principles of linear momentum and angular momentum that may be important for having the operation of a fluid machine.

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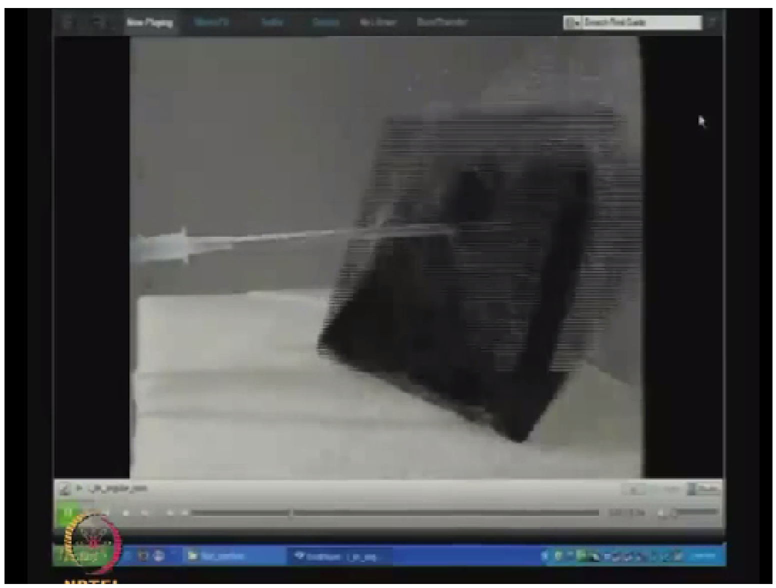

So first let us look into this example which we will see soon. So just see that there is a plate on which there is as jet which is falling, right. This type of examples which we have seen earlier when we were discussing about the linear momentum conservation using the Reynolds transport theorem.

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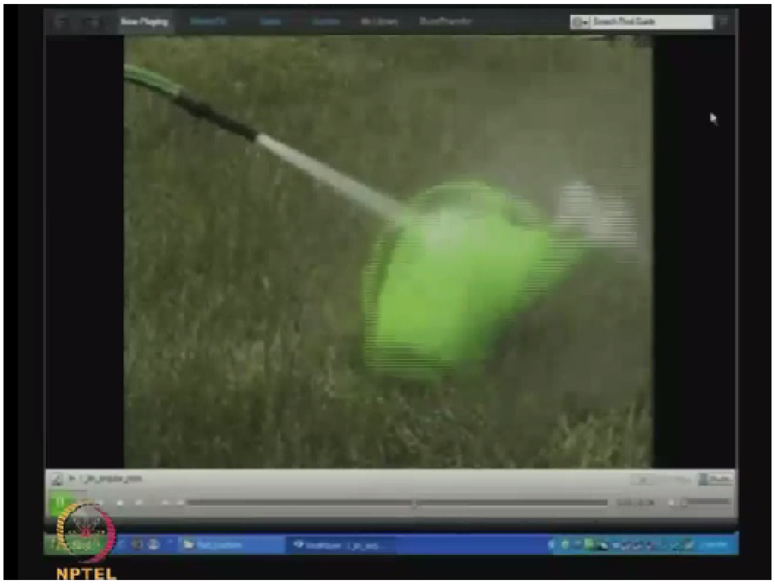

So here you can see that these examples are linear impacts.

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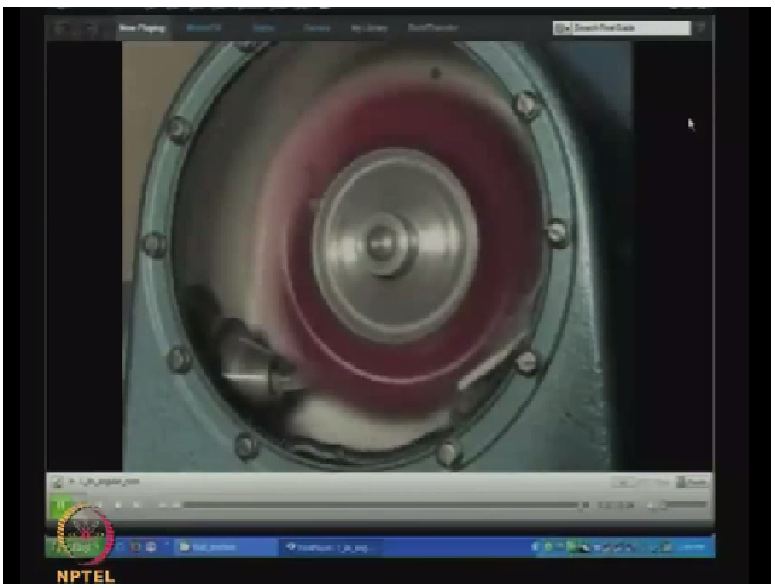

Now look at an example. here you see there is a rotor. This is known as a Pelton wheel. We will see that later on that it is basically a sort of a part of a turbine. See there is a jet which is falling on the blades of the wheel and it starts rotating. So it is a transfer of energy which creates a change in angular momentum.

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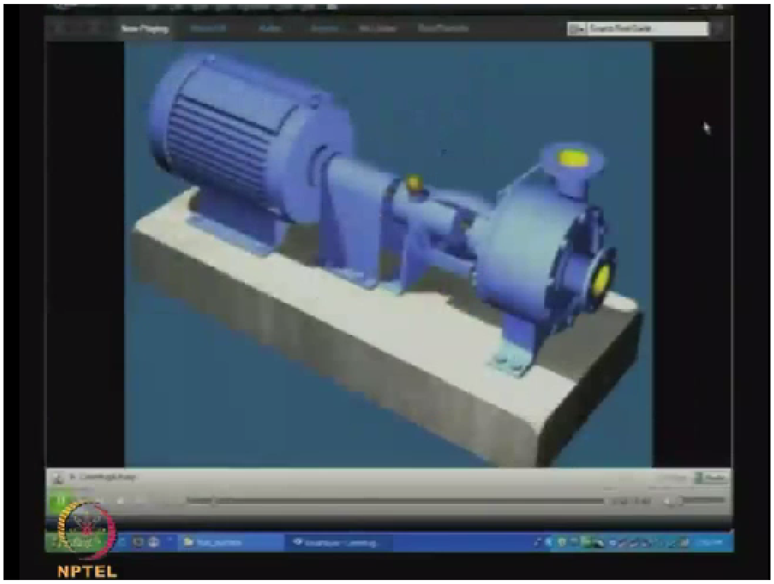

Now we will look into an example which is called as a centrifugal pump. We will first start with the pump and just look into this example, it is just a visual model but we will give you a sort of idea. We will play it once more. Just try to visualise it and we will concentrate on the different parts. So first just have a look on what are the important parts that maybe there for a pump. It is just important to have a feel first that what it is about and then we will concentrate more on the intricate parts.

And the part that we will analyse is basically the rotor, not the full part but let us just play it again and let us see that what are the parts.

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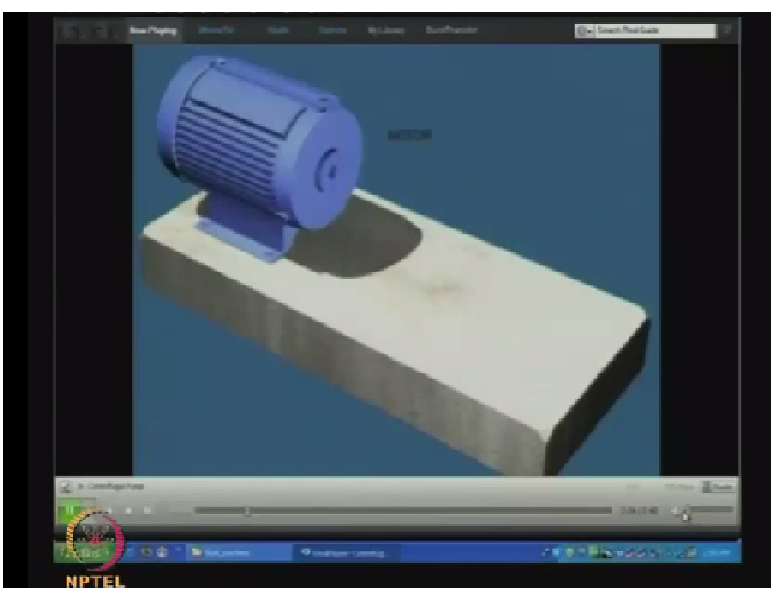

See first the motor, that is an electrical component.

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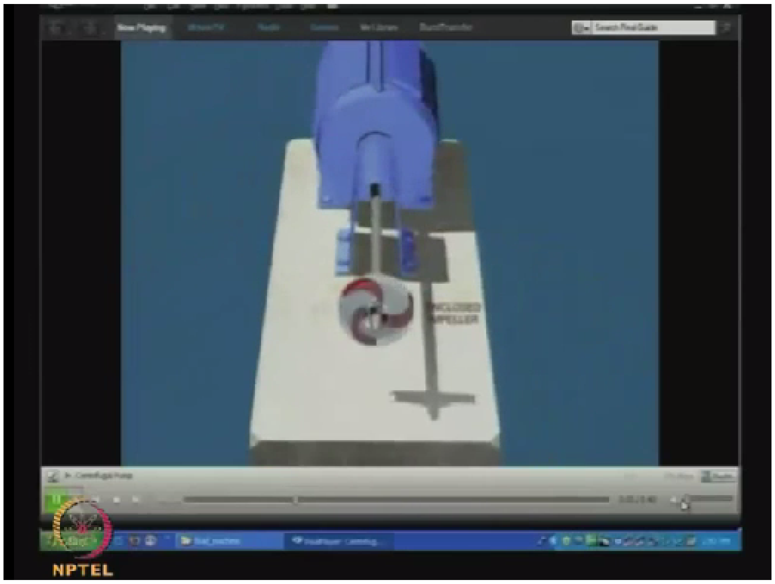

Then you have a shaft, right and you see that on the shaft, you have a rotor which is known as the impeller of the pump.

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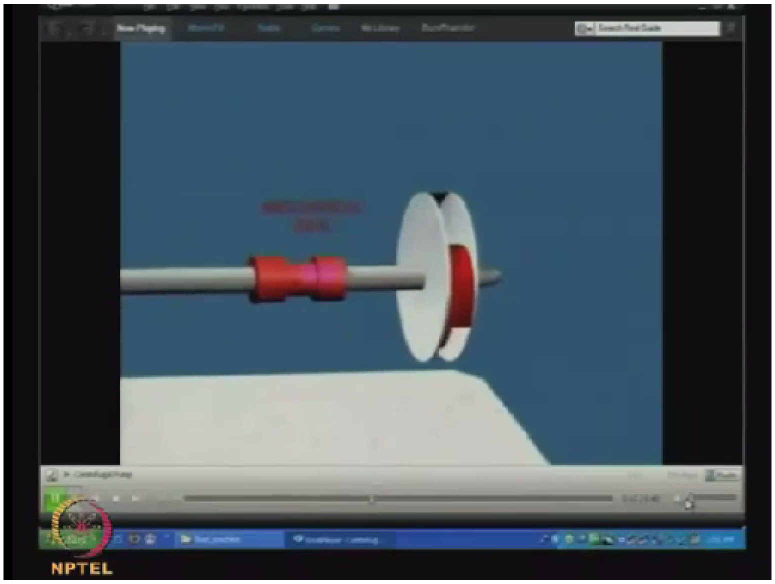

So what is the whole purpose, you see there is coupling.

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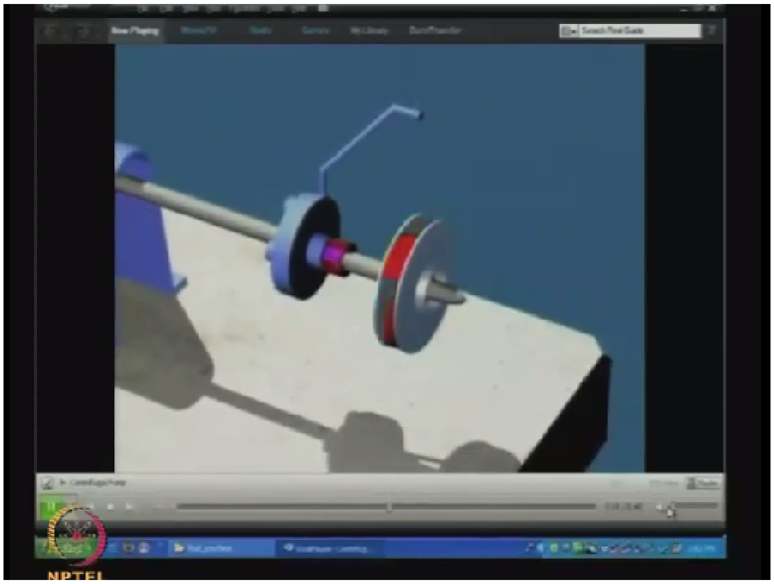

So what happens?

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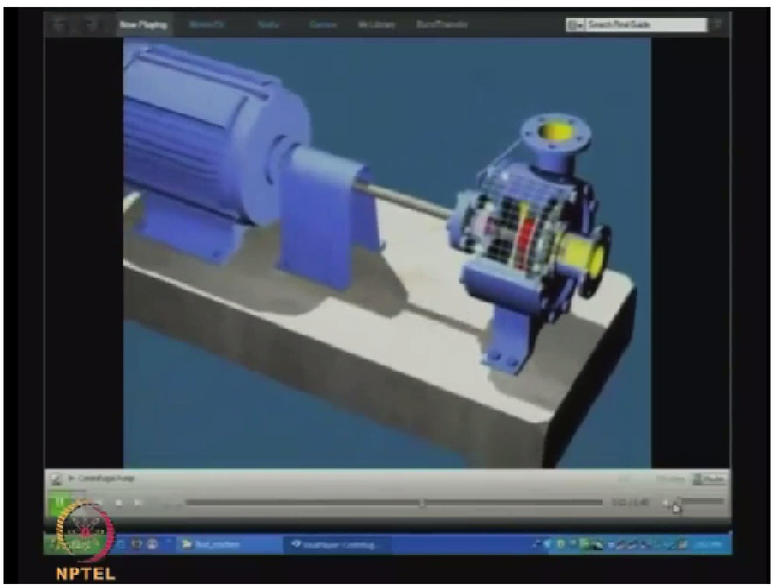

There is a motor which is inputting some electrical form of energy. So there is a shaft of the motor that is connected by a coupling to the shaft of the impeller, the name of the rotor is impeller, on which the rotor is there. So what is happening is, it is imparting some rotational form of energy to the impeller and the impeller therefore is rotating. Now a fluid will come and it will strike the blades of the impeller.

And it will have therefore a change in angular momentum because it is already rotating and the blade passage will direct the fluid to give it a change in direction and we will see that change in angular momentum will give a net torque and give rise to a net power that is developed and therefore a net head that is produced out of the fluid machine. And our next objective will be to formalise this a bit more and try to understand that if you have such a rotodynamic device, as an example a centrifugal pump.

So this device is known as a centrifugal pump. Name is quite obvious because it is rotating and sought of as if the centrifugal force is one of the key features that governs the behaviour of this device and we will see that how we can derive an expression for the head developed by this centrifugal pump. So we will consider the angular momentum principle for a rotodynamic device.

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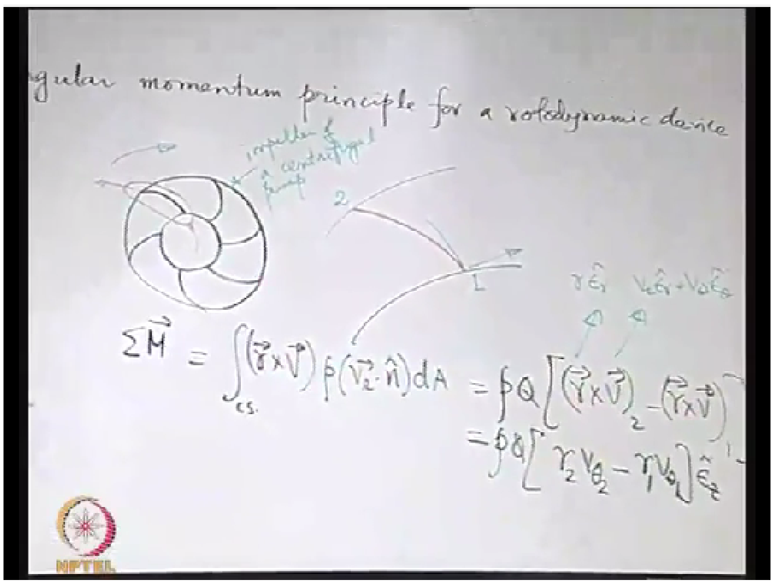

So let us just draw a schematic and say that this is for example is an impeller of a centrifugal pump. Just as an example. So now if you concentrate on these things, see these are like individual blades, okay. So these blades, what they do? So the fluid enters the blades and it leaves the passage which is adjacent to the blades. So the blades give a change in direction to the flow and because of the change in direction, you are basically having the change in angular momentum.

And to understand that, what we will do is, we will just isolate one blade. Let us say that you have an inner radius and an outer radius. Let us say these 2 are the inner and the outer radii lines and let us say that this is a blade and we want to figure out that what change takes place across these blade. So for that, let us or try to understand what happens at the inlet and the outlet. So 1 is the inlet and 2 is the outlet to the rotor which is the impeller. So this is an example of impeller of a centrifugal pump. To understand what is happening, what we will do is, we will isolate the drawing and draw it in a bit more magnified form of the blade.

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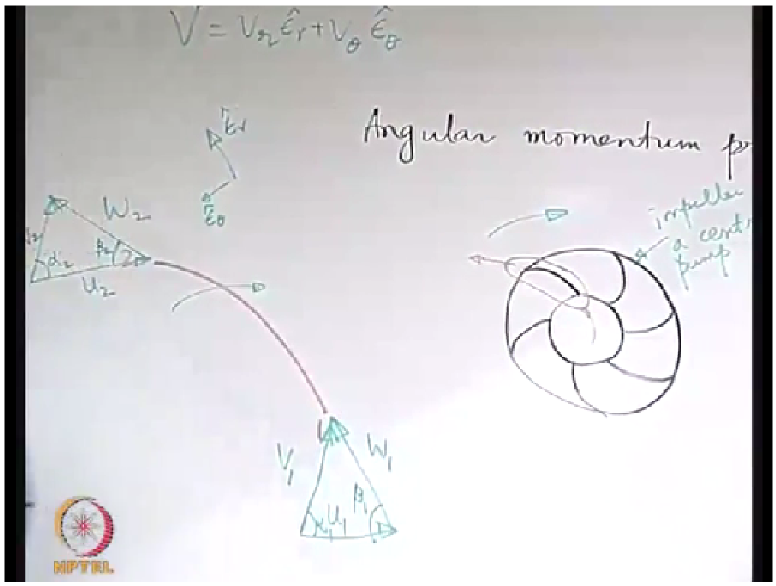

So first of all consider that when the fluid is entering the impeller, what it has? It has a velocity relative to the impeller. So let us say that this is the velocity that the fluid is having relative to the impeller. So these are the symbol that we will be using. Different books use different symbols but just we will be using some consistent symbols. So we will use W for velocity, relative velocity of the fluid, okay.

So W is the relative velocity with respect to the rotor here as an example. Now on the top of that, the rotor itself has a velocity which is the tangential velocity. So it is just like a tangential velocity at the point 1 which is tangent to the inner radius, okay. Now it all depends on what is the direction of these? It depends on whether it is rotating in the direction clockwise or anticlockwise.

So let us says that it is rotating in the clockwise direction. So that means it is rotating in the direction opposite to the way in which the blades are curved in this example. We will see what is the consequence of that and whether it is good to have the rotation in the other direction. In which direction, rotation should be better. All those details we will see but just for the sake of like drawing or constructing the figure, we have to assume some direction.

So let us say that this is the direction. So that is tangential and we give it a name U. So U is the tangential component of the velocity of the rotor itself and W is the relative velocity so the resultant velocity is the sum of these 2, the vector sum of these 2 which we say is the absolute velocity of the fluid. So V1 is sum of the velocity, tangential velocity of the rotor+the velocity of the fluid relative to the rotor, okay and the direction between U1 and W1 is nothing.

But the angle made by the tangent to the blade and tangent to the inner radius of the circle and that is known as blade angle. So this beta is given a name as blade angle. So it is sort of gives an orientation of the blade relative to the tangential direction of the rotor, okay. So beta is the blade angle. So this triangle that we have drawn is known as the velocity triangle at a given location. So here it is the inlet to the centrifugal pump. Now you come to the outlet.

So when you come to the outlet, again it moves out, the blade gives it a direction and it moves out with a particular relative velocity W2. It has a tangential component of velocity U2 and therefore, the resultant velocity as V2, very similar to the velocity triangle at 1, this angle is beta2. The other angle is given name as alpha. So this is alpha2. We are assuming that the rotation is in this direction.

Now we have to keep in mind that here we are bothering about 2 important directions. One is the radial direction; another is the cross radial direction. For a circular rotor, the cross radial is nothing but the tangential direction. So we have a unit vector, say in the radial direction epsilon r and unit vector in the tangential direction epsilon theta. So the velocity will have a component or a resultant as the relative, sorry, the radial component of velocity+the tangential component of velocity, Vr and V theta. Everything is in the same plane that we are assuming.

So the velocity may be resort in the radial and the cross radial or in this example, cross radial is nothing but the tangential component. Now with his background, let us try to see that what is the resultant moment of all forces with respect to the axis of the impeller or the axis of the rotor. So how do we do that? We use the Reynolds transport theorem for angular momentum conservation. So when we use the Reynolds transport theorem for angular momentum conservation, say we consider the controlled volume as the fluid in the blade passage.

And let us write resultant moment of all forces with respect to the z-axis, the axis which is perpendicular to the plane of the board. So this=integral r cross V…, right. The unsteady term is 0. We are assuming that it is a steady flow. So this is the left-hand side and so it may be let us just write in the vector form without looking for the component and the right-hand side is the area flux term that is the only term that is present.

So let us write it is terms of the individual components. First of all, see fluid machines are very complicated devices because the geometry itself is very complicated. It is not like a flat plate. It is not like a pipe of a very well known geometry, here the geometry is well-known but because of the complicated geometry, the velocity distribution is quite complicated. So for engineering analysis, basic engineering analysis, certain simplifications may be made.

Some of the simplifications are that, we are assuming that the velocity profiles are sort of uniform at the inlet and at the outlet so that the variations or the local variations with respect to the theta, that we are not considering for this analysis. Then you can see that this you can write like first of all Vr dot ndA integral of that, first of all if r cross V is not a variable. It is not varying over the area of the flow, then you can take it out of the integral and the remaining one is nothing but rho*the volume flow rate.

So it essentially becomes rho * the volume flow rate * r cross V at 2…, right. Keep in mind that for outflow V.n is positive and for inflow, it is negative, that is how this - and + sign have come, okay. Now r cross V, so let us write that in a vector form. So what is r? r is nothing but r * the unit vector along the radial direction and what is V? VrEr+V theta E theta. So what is r cross V? Yes? So rho Qr2V theta2, and what is the direction?

Direction in the z direction, right? So we will write the direction separately, * the unit vector along the z direction. Now because of these moments of all the forces, you have a net power or rate of work done. Whether it is work output or work input, it depends on the type of the device whether it is imparting energy to the fluid or it is taking energy away from the fluid. Accordingly, the sign of the power will change.

But the magnitude of the power will always be given by this principle. So what is that power?

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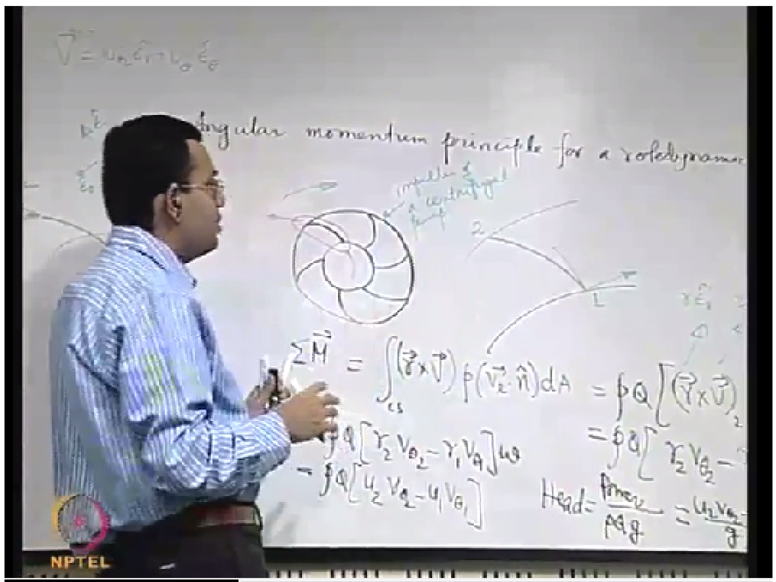

So consider the magnitude of this with respect to the z axis, that times the angular velocity. So that becomes rho Qr2V theta2-r1v theta1*omega. We have not really bothered about the algebraic sign of omega plus or minus, all these things because anyway the algebraic sign of this will depend on whether it is work producing or work absorbing device, okay. So if you want to have a power output, that is energy is being important to the fluid, then this you expect to be positive that is there is a net work output but if it is negative, that means it is a net work input.

So now if you look into the velocity triangles, can you say what is omega*r1 from these velocity triangle? What is omega*r1? What is U1. U1 is omega*r1, right. So this therefore becomes rho Q*, and similarly, omega*r2 is U2. So this is U2V theta2-U1V theta1, right. As we have discussed earlier that in many times in fluid mechanics and also in fluid machine applications, we referred to not just the power but expressed in terms of length unit or head.

So if we say that what is the equivalent head? Head is nothing but the power… because if you see rho*Q is the rate of mass flow. So M.*g*the head or h is nothing but a power unit. So we want to express it in terms of a power unit, that is U2V theta2-U1V theta1/g. This sometimes is known as Euler head in a rotodynamic device.

It is as good as writing a modified energy equation in a rotating reference frame because eventually if you look in a viewpoint of the impeller of a centrifugal pump as an example and if you are sitting there that means you are sitting on a rotating reference frame. Now of course this general purview of the rate of change of angular momentum and therefore the net moment of some force with respect to the axis of the rotor is valid no matter whether it is work producing or work absorbing device.

But we will start with an example that we start with work producing device or rather basically, it is a work absorbing device with which let us start, that is it absorbs the energy from the electrical input that is given by the motor and somehow it imparts the energy to the fluid because of that. So that example is a centrifugal pump for which we have drawn this impeller. So we will now go in to a bit more details on what happens across the impeller of a centrifugal pump and for that referring to these velocity triangles may be very essential.

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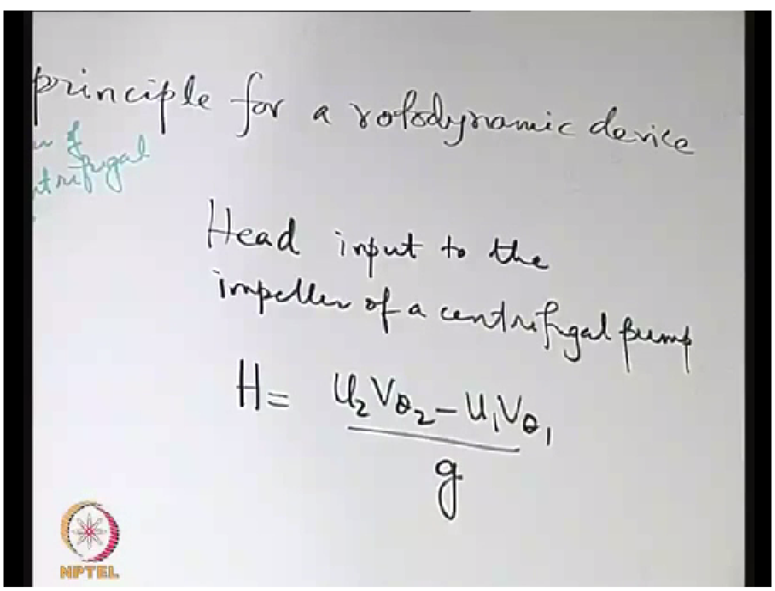

So we will look into the head develop or rather the head input to the impeller of a centrifugal pump. The head developed will be equal to this one if there is no loss but in reality there is some loss and therefore, the head developed is a fraction of that one and that fraction is known as hydraulic efficiency. We will come into that subsequently but first let us try to see that how we can simplify this from the velocity triangles. So let us consider the velocity triangle at the outlet. So what you can write, so if you just break it up into components, just for clarity.

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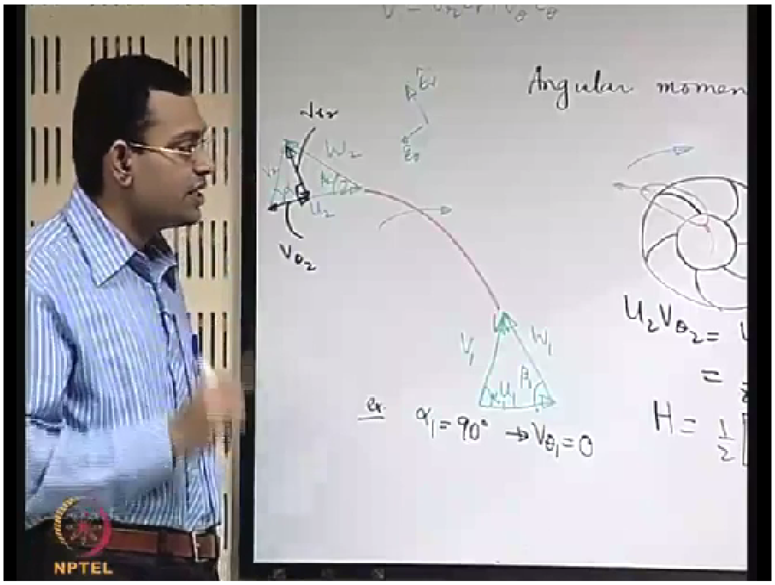

This is what? This is V theta2 and this is Vr2. The theta and the r components, okay and this angle is 90 degree. So you can write U2V theta2 as what?

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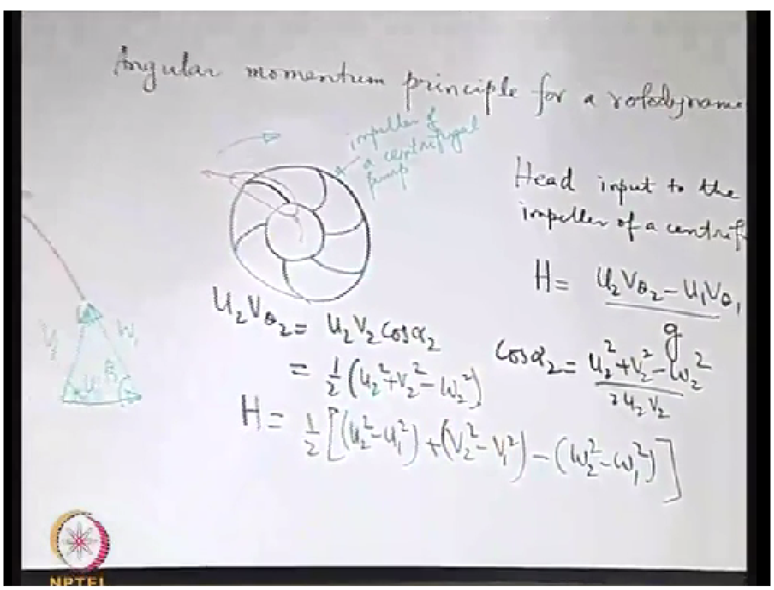

U2*V2*Cos alpha2, right. Now from the properties of triangles, you can write Cos alpha2=U2 square+V2 square-W2 square/2U2V2, right. Therefore, U2V theta2 is as good as U2*V2*Cos theta2 that is 1/2 of U2 square+V2 square-W2 square. Therefore, the head becomes 1.2*U2 square-U1 square+V2 square-V1 square-W2 square-W1 square. This is a form in which you can write which is independent of the blade angles but just dependent on the velocity components, just a different form of writing the same expression.

The next thing is that to develop a bit more insight on the implications of the blade angle on the performance of the pump, To do that, let us make an assumption that alpha1=90 degree. When alpha1=90 degree, what you can see from the triangle is you must have V theta1=0. That means radial, the entry at the inlet is totally radial, right. You do not have the tangential component of velocity at the inlet.

So this is also inverse called as radial entry at the inlet and this is a very common case. Why you want to do that? Just look into this expression. See when one wants to design something, there is a purpose. You see that it is U2V theta2-U1V theta1 and these are all algebraic positive numbers. So the maximum head that may utilise when this is 0 and V theta1 is 0 and alpha1 is 90 degree. So that is why alpha1=90 degrees is a good design.

Because it allows you to utilise the maximum head by having the negative term as 0. Now if you consider that as a case, then for that let us write what is H?

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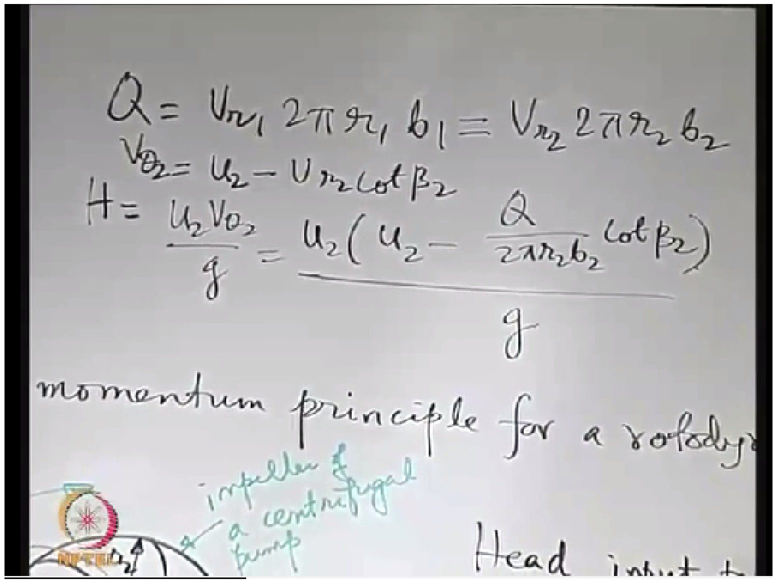

Now we have to keep in mind that when you are doing say an experimental study with a pump, there are certain common things which you can measure. What are the common things? One is the flow rate. So what is the rate of flow in terms of the volumetric rate, that is may be in terms of meter cube per second that type of unit. So that you can find out. When you know that what is the flow rate, what is the radial component of the velocity, then you can relate that with the continuity equation if you know what is the area over which the fluid is flowing.

So the radial component of velocity is the velocity normal to the direction or velocity normal to the rotor and how it is related to the flow rate. So before writing the expression for H, let us try to write that. So Q=VR*what? Time and area. So what is the area over which the fluid is flowing. Let us assume that these blades are very thin. If the blades are very thin, then almost the entire area is 2pi r, where r is the local radius.

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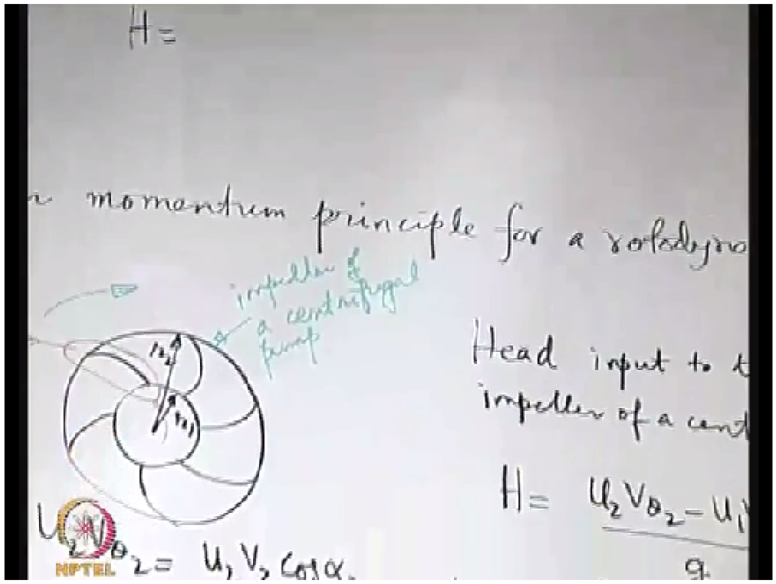

You may have 2 different radii here. One is say r1 and another is r2 which we have used in our symbolic expressions. In between you may have any r, let us say r=r1 or r=r2, whatever it is. So if the thickness of the blades are neglected, then you have the total area of flow available as 2pi r*the width of the blade perpendicular to the plane of the figure. Let us say b is the width of the blade perpendicular to the plane of the figure and that may vary from inlet to outlet.

So you can say that Q=Vr1*2pi r1*b1. It is same as Vr2*2pi r2*b2. The b1 and b2 are the widths of the blade at the inlet and the exit respectively. Now that means if you know what is the geometry of the pump, so you know the radius r1, r2, all these things. You know the blade width. If you measure the flow rate, you can get the radial component of the velocity. So if you know the radial component of velocity, how to relate that with V theta2?

See you also know U2 in way why? Because you know what is the angular velocity with which it is rotating. So r2*omega is U2, right. So you can write V theta2 as what? U2-Vr2Cot beta2. Just look into the triangle. So this total length is U2. This amount of length is VR2Cot beta2. So this is V theta2 that is total U2-Vr2Cot beta2, okay. So H you can write what? U2*V theta2/g.

So U2*U2-, in place of Vr2, you can write Q/2pi r2b2*Cot beta2/g, right. Now this gives us simplified enough expression to have an assessment on the implications of the blade angle at the outlet beta2. Now to get an idea of the blade angle, what we are seeing is that what is the convention that we have put for the blade angle. So you have the directional of the tangential velocity which is like this in this example.

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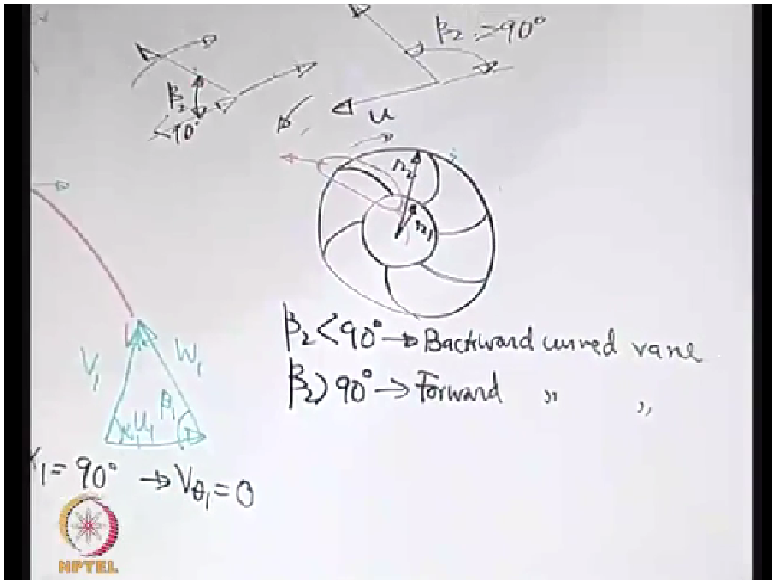

You have a direction of the relative velocity and you just make the angle between them. Let us say that the impeller is now moving in the opposite directions, that is it is instead of moving clockwise, it is moving anticlockwise. Then this is the direction of U, if it moving in the anticlockwise direction and then this is the velocity relative to the flow and you see that this angle, what is the convention?

The convention is that you have basically, this is the direction of the flow, this is the directions of whatever is angle contained between those 2 by considering the common apex, 180 degree-that that is what you are actually calling as beta. So then this should be called as a beta, just by following the same convention. So here in this case, when it is rotating in this way and the fluid is coming out in this way, by this example where the rotation is this one, we have beta, beta2.

Here this is beta2, here this is < 90 degree and here you have beta2 > 90 degree. So what is the peculiarity? Beta2<90 degree is known as a backward curved vane; vane means blade basically. So backward curved vane means, the tangential velocity is in the forward direction but the blade is oriented backwards to that. That is why this is called as a case of a backward curved vane.

On the other hand, if the tangential component of velocity and the curvature of the blade are oriented in the similar fashion, then it is called as a forward curved vane. So beta2>90 degree is called as a forward curved vane. A special case, may of course be beta2=90 degree. Now first of all you have to remember that this is theoretical. This does not consider any non-ideality in the analysis but it is good enough to have a sort of an insight.

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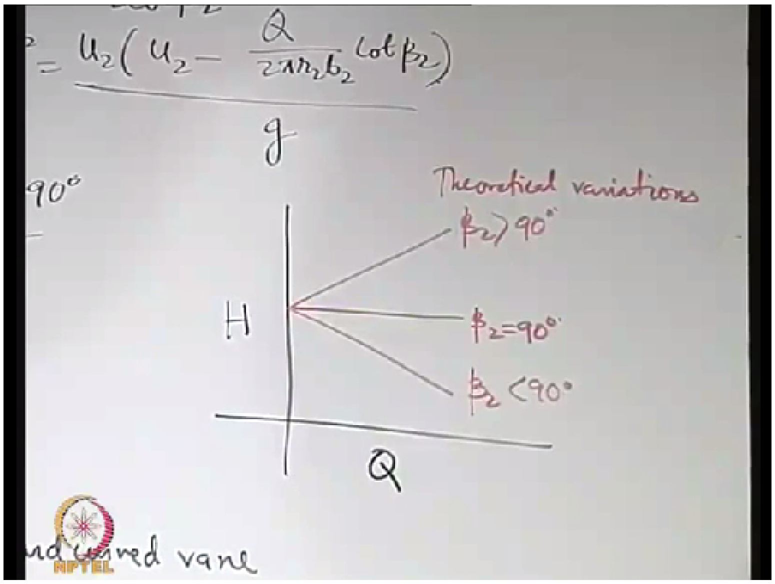

So let us say that we plot H versus Q, okay for different cases. One is beta2<90 degree. Another > 90 degree, another = 90 degree. First of all, if beta2=90 degree, then how will it look? It will be a constant, right. If beta2<90 degree, then Cot beta2 is what? Positive, so that means you are having a positive number subtracted from this. So with increase in Q, it should decrease and H linearly varies with Q.

So it should be a linearly dipping variation with beta2<90 degree. Similarly, with beta2>90 degree, it will be like this. Remember these are theoretical variations. Now we will look into the implications of beta2 by referring to the theoretical variations and then with some more practical considerations. First of all, let us look into the velocity triangle. Let us say that you have now in place of this velocity triangle, a case where you have beta2>90 degree.

So if you have beta2>90 degree, that means if it is still rotating in the same way, the blade orientation will be the reverse.

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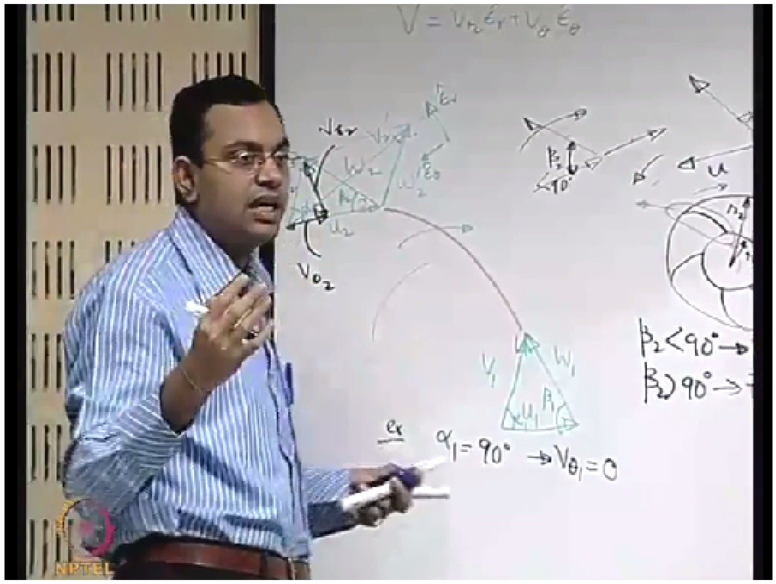

It will not be backward but it will be forward. So when the blade orientation is reversed, that means what happens? So if U2 is the same, let us say that it is rotating at the same angular velocity, the same radius r2 but what is the only change? The only change is now the relative velocity direction has changed because blade orientation, why it is important? It gives a direction orientation to the relative velocity.

So now with the forward curved things, say the relative velocity direction becomes this. If the flow rate is the same, we have to keep in mind that whatever is the relative velocity, its radial component should be same as before because the radial component denotes or determines what should be the flow rate for a given geometry of the impeller. So now if this becomes the new W2, then this becomes the new V2, right.

So the new V2, you can see is much > the old V2 and that means when the fluid is leaving the impeller, it is leaving with a higher kinetic energy and when it is leaving with a higher kinetic energy, that means that energy, kinetic energy has not, so whatever is the energy with which the fluid is leaving the impeller, that means that energy was not utilized or in other way that energy has to be well utilised because I mean the thing is it has developed the kinetic energy but it has not yet been utilised because it has not yet left the impeller.

So when it should leave the impeller, it should leave in such a fashion that it should give an equivalent rise in pressure or may be a static lift. Say if you are having a fluid leaving an impeller with a high kinetic energy, your purpose here is not to get the kinetic energy. Your purpose is to get an equivalent rise in pressure or may be a height as an example. If it is a fan, it is fine but if the purpose is pressurisation or change in height, then what you expect?

You expect is that this has to be, this kinetic energy somehow has to be converted into equivalent form of like say pressure energy, say rise in pressure and that has to be judiciously taken into account. To take that into account, there is something, there is some arrangement integrated with the impeller of a pump and that is known as a volute casing. So what it does? Basically you have the, let me just write a bit clearly.

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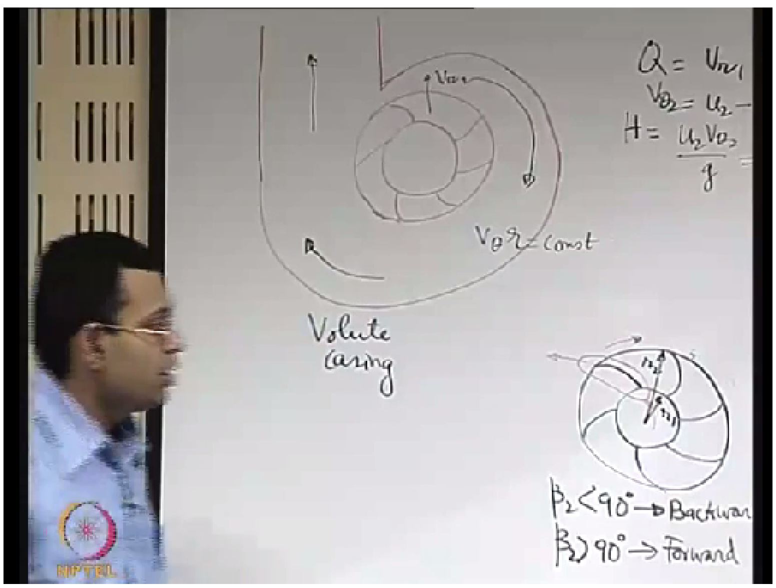

If you say have an impeller like this, then let us say that we are having a casing around the impeller. How is the casing? The casing is such that its area is continuously increasing. I am just magnifying it a bit too much but that will give you a sort of clarity in the nature of the casing. So the whole idea is that the fluid is leaving the impeller, entering the casing, coming like this and going out.

In the process, what is happening? This is known as a volute casing. So you can clearly see that as the fluid is moving around, the area is sought of increasing continuously and therefore, its velocity should continuously decrease and if energy is conserved, if there are no loses, then that equivalent decrease in velocity should be compensated by the increase in pressure. So it will sort of utilise the form of energy but not the kinetic energy but converting it into an equivalent pressure here, that is what it is trying to do.

So in the volute casing, what happens? See the fluid, now why the shape should be like this? So the fluid enters with a constant radial velocity VR, sorry exits the impeller with a constant radial velocity. That means it enters the volute casing with that radial component of velocity say VR2. On the top of that, it is undergoing a change in the direction such that V theta*r=constant, that is a free vortex because you are not having, so this is the V theta for an irrotational vortex but is not the vortex flow.

It is something more complex than a vortex flow because a vortex flow will not have Vr. Now you have a Vr. On the top of that, you have this V theta where V theta*r is a constant. So this kind of thing is there because you are, see when it was in the impeller, there was some moment of forces which were there acting on it. When it is leaving the impeller, you are not having any moment of force acting on that, that means angular momentum is conserved.

So if you are not, of course that means you are not considering any dissipation torque. So the dissipation torque because of the viscous effect that is neglected for this. So then you have a resultant motion which is a superimposition of Vr and V theta*r=constant and that gives the shape of spiral streamline. So if you find out what are the corresponding streamlines. The corresponding streamlines are a spiral shape.

So this volute casing geometry, the envelop is also given the same spiral shape so that the streamlines have a smooth flow within that. So this geometry of the volute casing is designed just according to the shape of the streamlines which is because of the resultant velocity with a constant Vr and V theta*r=constant and that basically is a collection of spiral streamlines. So now this entire activity has to be more strong or more important when?

It has to be more strong when the blade is forward curved because then you have b2 as more. So this entire recovery of the pressure energy from the kinetic energy that activity has to be taken much more seriously in that case but that is not all. The more important thing is that what are the other non-idealities which occur within the impeller itself and let us try to look into that. One of the important non-idealities is that, when the fluid leaves the impeller, let us say that this is the impeller.

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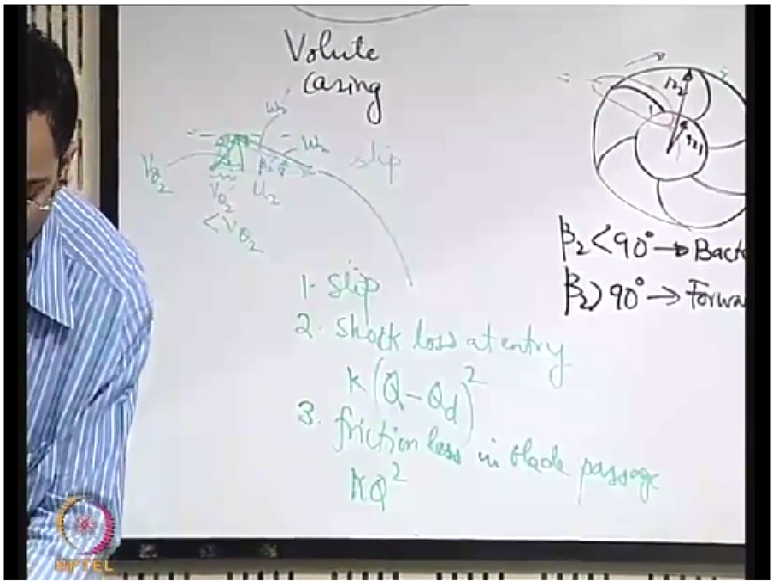

Let us say that this is the impeller and the fluid is leaving the impeller. We are assuming that it is leaving very smoothly. That is it is leaving according to the blade angle which is designed but in reality, it may not leave according to the blade angle that is designed. Why it may not leave according to the blade angle that is designed? If you see let us say that this is, first of all let us assume that it may not follow the blade angle that is designed because if it follows the blade angle that is designed, that is the ideal situation, that means sort of it just smoothly comes out.

So we say that it comes out without any slip but if there is some sort of a deviation from the blade angle, then it will come out like this with a different blade angle, say this is beta2 prime. This beta2 prime is different from what is the original beta2 and this phenomenon is known as slip in the exit of the fluid from the impeller. So because of this what happens? Again let us say that we have a constant that the volume flow rate has to be the same.

So if the volume flow rate has to be the same, the radial component of velocity has to be the same and the tangential component of velocity U, that is omega*r, that is also same because angular velocity is the same and the radius of the impeller at the outlet is also the same. So the result, the net effect is that when you draw the velocity triangle, this is new W2 and this is old W2.

If you consider now the resultant velocity by considering that the radial component of the velocity remains the same. Now what you have? You have a V theta2 which is < the original V theta2. The original V theta2 was this one, okay. So because of this slip, the effective blade angle at the outlet gets changed. So the V theta2 becomes less and because of the V theta2 becomes less, the work output also or rather the head developed also that will become less.

So that is a loss considering slip. Then if you consider the entrance to the blade, that is at the point 1. There also it may not be possible that the fluid enters smooth to the blade. It may not enter smooth to the blade and that means again the relative velocity may not be exactly aligned tangential to the blade and then there may be a loss because of that, that is known as a shock loss at the entry.

So the shock loss at entry. So these are the non-idealities and this higher and higher the velocity, more and more chance. Higher and higher means the flow rate, more chance is that there will this loss. Usually the shock loss is empirically related to the square of the flow rate. So this Q is the actual flow rate. Qd is the design flow rate. So if there is a deviation of the actual flow rate from the design flow rate and there may be a shock loss at the entry.

Why? It is considered a square of these because typically the losses are characterised as a fraction of the kinetic energy of the fluid which is like V square form. So this is some constant*this. So that is one of the losses. The third loss and a very important loss, the frictional loss. Friction loss is the blade passage.

So if you have frictional loss in the blade passage, then that again if it is a highly turbulent flow, that is like of the form kQ square, like we have got an idea, qualitative idea of why it should be so. So if you consider the losses, so these losses mean that now whatever head you are developing, is not the theoretical head but some head which is less than that.

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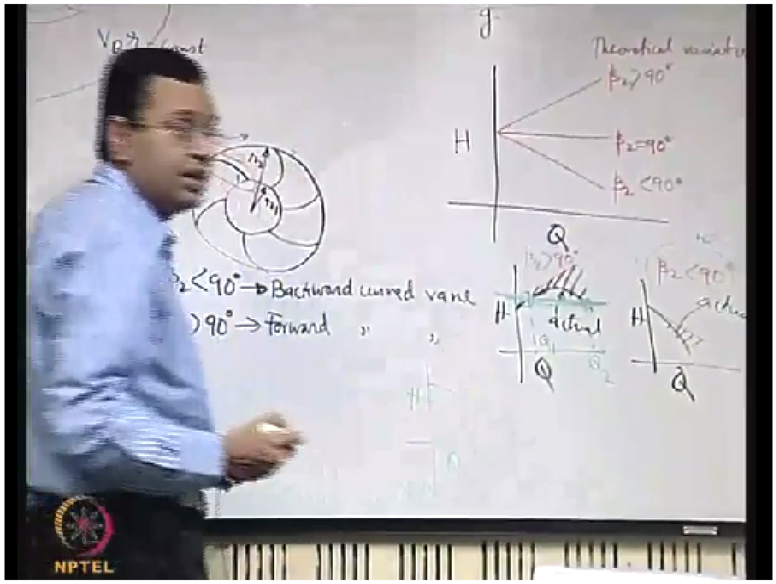

So if you plot the HQ curve for a forward curved vane and a backward curved vane. So if you have this one as the theoretical, then with some loss, the actual curve may become something like this, okay. Whereas if you have this as theoretical, with some loss the actual curve maybe something like this. So this shaded area represents a sort of loss. So this is the actual curve. So the actual HQ curve, now we have 2 possibilities.

So this is for beta2>90 degree. This is for beta2<90 degree. Out of these 2, which one should we prefer? What is the problem if you have beta2>90 degree. Let us say that you want to have or you are developing a particular head H. Consider a particularly head H like this, say a horizontal line. So if you consider a particular head H, a horizontal line like this, then you can see that for a particular head H, you could get 2 operating points, right.

That means while developing a particular head, the pump might have a fluctuation in flow rate between Q1 and Q2 and Q2 and Q1 like this and that is sometimes known as surging in a fluid flow system and that is something which is undesirable because it is ambiguous, for a given H you would have 2 operating point satisfying that. Whereas here that type of possibility is not there.

So keeping all these factors into account, the backward curved vane is something which is considered to be a more practical thing for design implementation of centrifugal pumps and that is why beta2<90 degree is what is the common one and you have the usual HQ curve like this. One important thing is, when you have Q=0, you have a particular value of H. That means even if there is no flow through the pump, there is a particular H. What is this H? This is just U2 square/g, right. So why is this H there?

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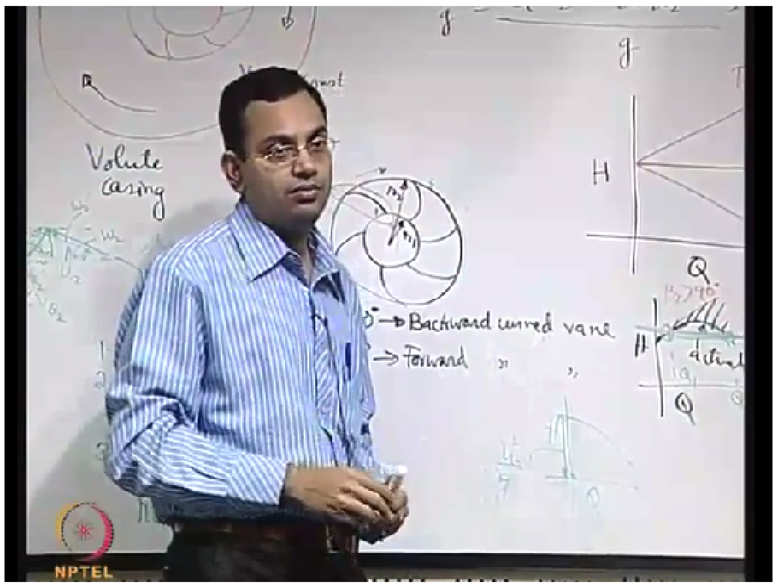

Even when you have Q=0, there is some H. So why you require this H? So this is some head that you need to develop to just overcome friction because before initiating the flow rate, you must have a threshold head or energy to overcome the frictional effects. So this is a threshold head or a threshold energy that needs to be available to overcome the friction and that is why it is not that at Q=0, H is 0 but some H to minimise or to overcome the frictional effects.

Beyond that if you have Q, then H will go down because some H will be consumed to maintain the flow. Let us stop here today. We will continue again in the next class. Thank you.