Fluid Dynamics And Turbo Machines.
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Part B.
Module-2.
Lecture-4.
Representation of Turbo Machines and Definition of Velocity.

Good afternoon, I welcome you all to the week 6 for the lectures on fluid dynamics and Turbo machines. In the last week we have talked about different types of Turbo machines and we have shown you some diagrammatic representation of Turbo machines. Today we will talk little more about how to represent the Turbo machines and what are the commonly used views for Turbo machine particularly the impellers and we will talk about the different velocities that are present. So to start with we are talking about the presentation of impeller and in the front view.

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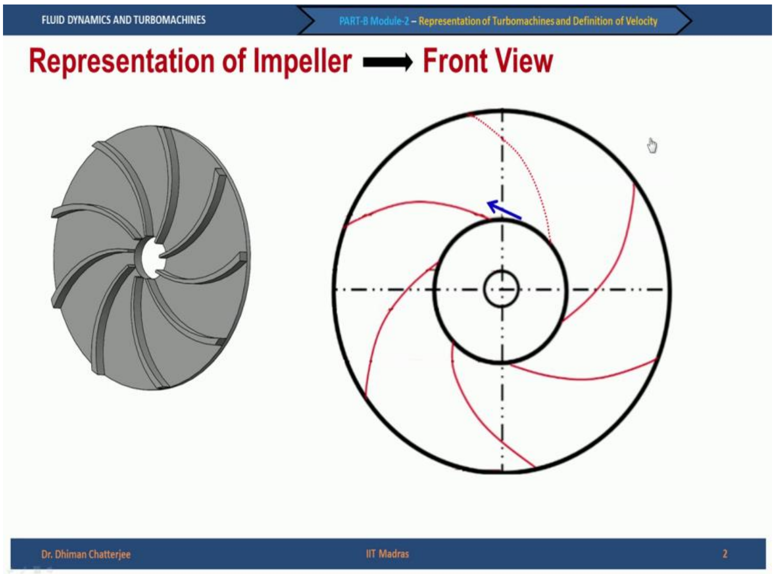

You have already seen this impeller which is a semiopen or it can be even a closed impeller but the front shroud has been removed for the sake of clarity. The blades are visible and when I look directly facing it in the front view, I get a picture which is shown schematically here. These lines represent these blades, of course for zero thickness, the thickness of the blade has been ignored here and we can see the hole for which is meant for fluid intake as well as for shaft.

This is also sometimes known as the blade to blade view because I can visualize the flow that is taking place in a vane passage between the 2 blades. But there is yet one more representation of an impeller which is very important in Turbo machine work and in Turbo machine literature, this is known as the meridional view.

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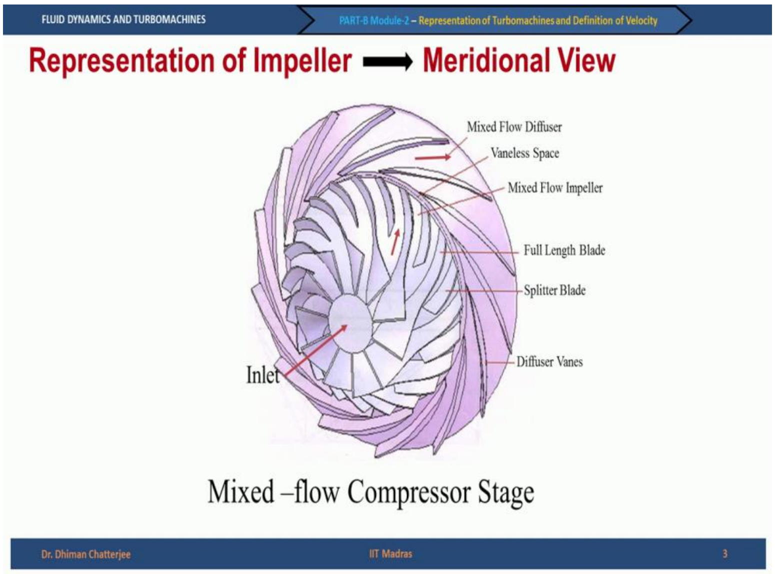

Here is a picture of a mixed flow compressor, the fluid enters as shown here, it goes through the blade passage and then it goes through some blades which are stopping abruptly you may think, these are called the splitter blades, we will not go into the details of the splitter blades here for this course and then ultimately there are spaces in which the flow diffuses out, we have the diffuser actions. This is a mixed flow compressor, you have already seen the mixed flow impeller in the earlier lecture. So how do we reconcile the 2 views? The solid model shown here and the view that was shown in the last week.

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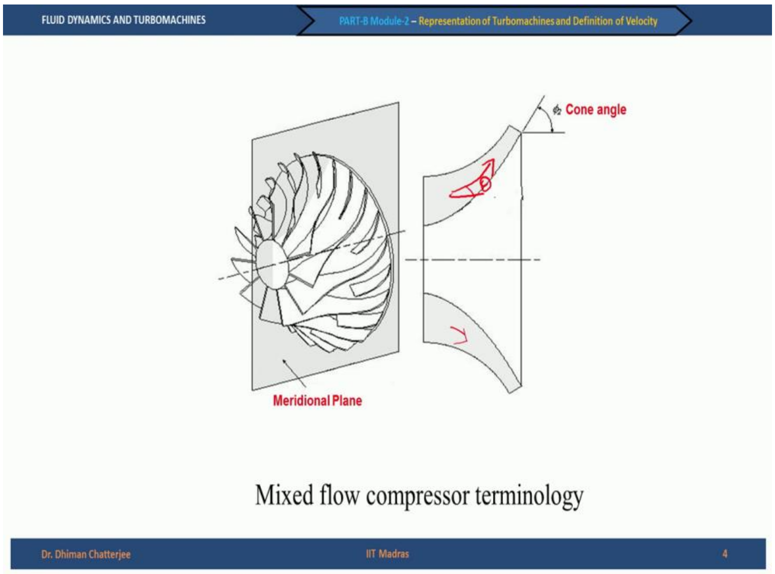

To understand that, now we bring in the concept of how to define a Meridional view. So to define a Meridional view, what we do is we pass a plane passing through the axis of the impeller in such a way that it cuts the blade and gives me the picture. So on the left-hand side I can show the full impeller I have just now shown you and this is a plane which contains the axis of the impeller as shown and once we take it out we can show the usual representation of a mixed flow impeller and if you remember we have talked about the direction of the flow and we can represent the direction of the flow as a mixed flow with an angle which makes with the axis.

So you know that according to my previous definition this angle Theta is neither zero nor 90 degree as it should be. This is a little more difficult geometry, so what we will recourse to is a use of a simpler geometry which is a radial flow machine. And I will first show you a radial low impeller and then talk about the machine in detail. So let us look at a radial flow impeller very closely.

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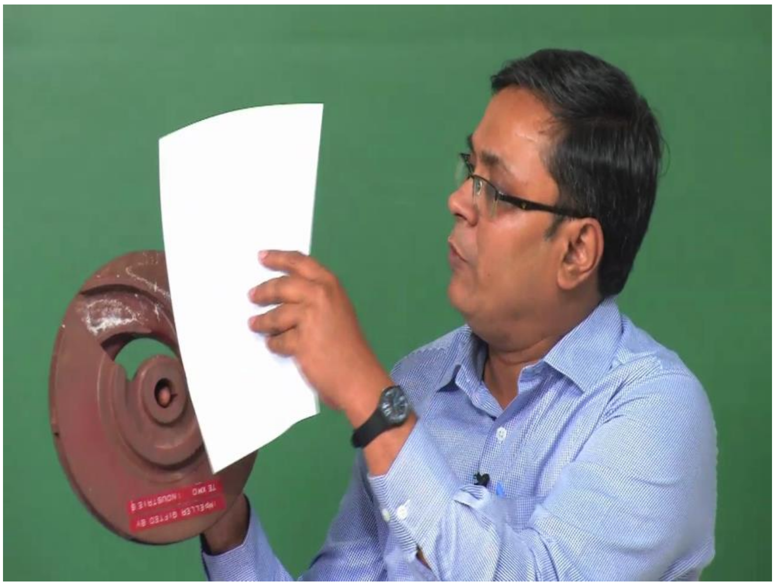

This is the vane and this is the next or the neighbouring vane, this is another vane and this passage which shows the my fingers inside between the 2 vanes is called the vane passage. And the flow in this case comes from the smaller radius to a larger radius, all right. Now if you imagine that I passed a plane through this containing the axis, then what will happen, this plane will cut the blade, this blade in 2 halves. So this plane, imagine there is a plane which passes through the axis, then what happens, this plane will cut the blade into 2.

And as a result if you view from the side, what you will see is a portion of the passage which is in this vane passage and a portion in that next neighbouring vane passage. When you look at these 2 vane passages, we cannot form a complete picture of what is happening inside the vane passage from the leading edge to the outlet. But what we need for a better understanding of a Turbo machine and better understanding of flow inside the impeller is a knowledge inside the vane passage. That means the normal sectional views or the normal side view is that we see will not work for an impeller.

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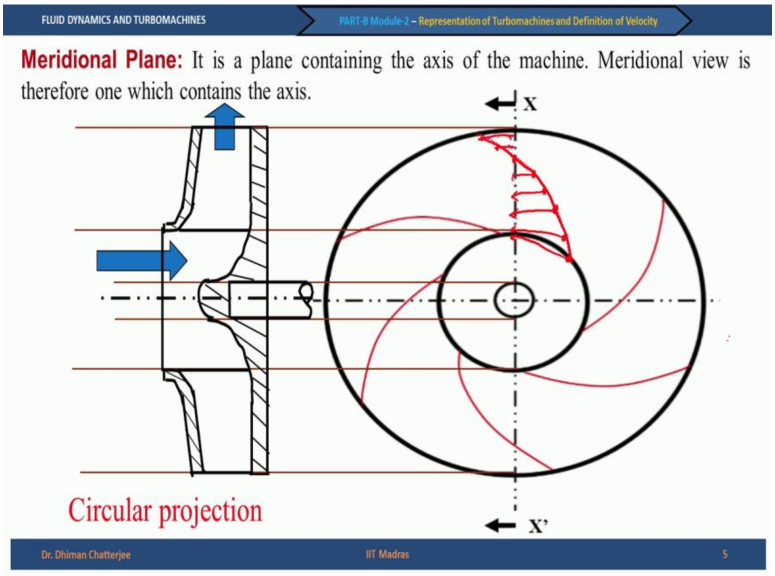

And hence for this type of radial flow machines I will talk about a different method of representation and that I will show in the next slide. So continuing from what we have seen just now with the impeller I can say that we are talking about a Meridional plane which is a plane containing the axis of the machine. Meridional view is therefore one contains the axis and this is the front view, I have taken a plane, the normal side view could have shown me by X to X prime and this is the view you traditionally see with the meridional views we have already established in the 5th week of the lectures.

And so let us see how we get this view from the X-X plane, X-X prime plane that we are talking about. So what we will do is we are considering one particular vane passage which gets cut by the plane. Just now I showed you in the real model a blade gets cut if you pass a plane to the axis, that is a meridional plane. So if I am trying to visualize this plane from the sides, then what I should see is I will be seeing both these meridional vane passage as well as the next neighbouring vane passage which is not desirable.

So what we do is we project each of these points along the circumferential on this line as shown here. So what you now see is you have now taken each point on the blade and then projected it not directly but by what is known as the circular projection and when you do this you will see what is known as the circular projection. So I repeat that if you take a plane which passes through the axis of the impeller, then it would have cut the blades in such a way that if I look from the sides I will see that 2 vane passages, I have one vane passage and its neighbour.

However if we instead of cutting the blades and looking at it in this fashion, if we now take a circular projection by which I mean that all the points on this blade are projected along a full circle onto this line X-X prime, then I will get the picture on the left which is known as the meridional view. And this is the most useful view in Turbo machines and you will come across these views quite often in the course of the lectures that I will be giving.

Another thing that we have to keep in mind and I have touched upon this point while talking about thermodynamics is that many times we can represent the Turbo machine inlet and outlet as in and out as we do in thermodynamics textbooks but you would have noticed in the tutorial done on week 5, I have also represented a turbine, not just buying in and out, I have represented by numbers 2 as inlet and 1 as outlet.

If you now want to understand why I have taken 2 at inlet and 1 at outlet, then we have to look at what is known as the unified representation of both power absorbing and power generating machines. I must also state at this point that this representation is not the only way of representing, you can still continue writing in in and out or any other way but what I will be following the nomenclature, I will use the unified representation. So let us look at what is the basis for this representation.

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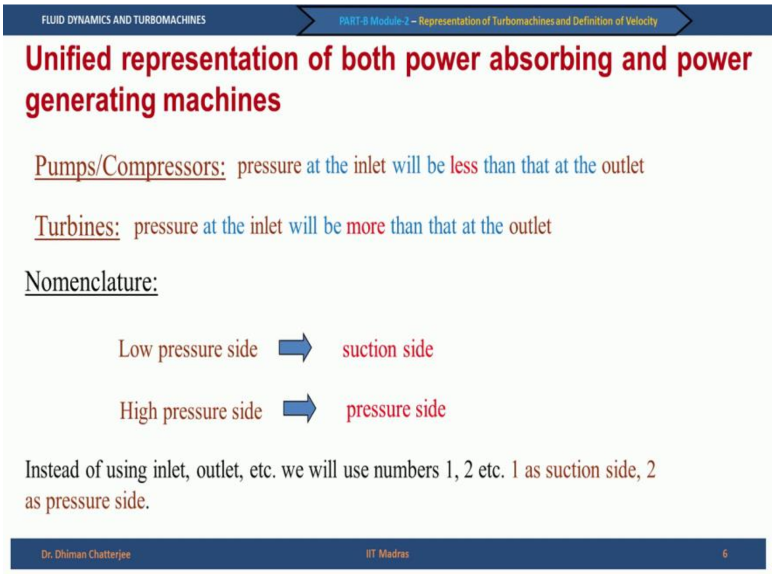

When I am talking about pumps or compressors, I can say that the pressure at the inlet will be less than that at the outlet, this is known. And for turbine it is converse, which means that the pressure at the inlet will be more than that at the outlet. Now this brings me of a nomenclature that I will use these terms low-pressure side as often as suction side and high-pressure side often as the pressure side. When I will say pressure side I will mean high-pressure side, you will get familiarised with these nomenclature as I proceed. Also instead of using inlet outlet etc., we will use numbers 1, 2, etc.

1 for suction side of the low-pressure side and 2 for high-pressure side or simply the pressure side. How to remember which one is and which one is 2, it is very easy. We know that 2 is greater than 1, so high is greater than low, so high-pressure side will be given the number 2 and the low-pressure side will be given the number 1 if there are instances where there are guide vanes then we may need to go to 1, 2, 3, etc. that is higher the number higher is the pressure. So please keep this in mind, higher the pressure, higher temperature, higher enthalpy and we will use the nomenclatures in that way also in that higher number is the higher pressure side.

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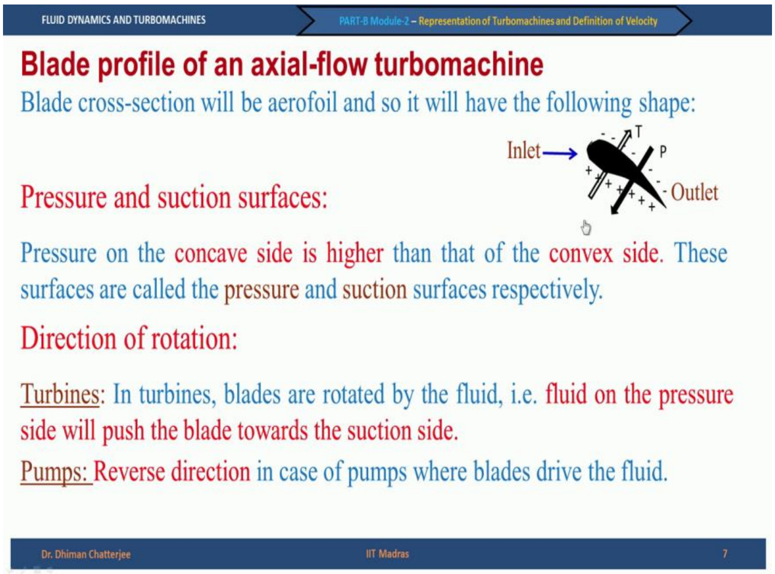

We have talked then shown you the radial flow machine. Now we will spend some time on axial flow Turbo machines like the axial flow compressors or the actual flow pumps or kaplan turbines which we have discussed in the last week. So the blade cross-section in this case of Turbo machine will be aerofoil and so it will have the following shape. You see that this is a typical shape of an aerofoil where the flow inlet is here, this is called rounded leading edge and it has a sharp trailing edge and this is the outlet.

So this is the usual shape of a blade, we will call it as an aerofoil profile. Now, this blade will have pressures on the concave side is found to be higher than the convex side. You might have studied in the fluid dynamics but in this course what we will say is that we will represent the high-pressure side with the + sign and the high low-pressure surfaces with the - sign. So we will call this high-pressure surface as the pressure surface and low-pressure surface as the suction surface.

Now depending on whether it is a pump or a turbine, the direction of rotation will be dictated by this high-pressure and low-pressure surfaces, so let us look at it. When we are talking about turbines we know that in case of turbines the blades are rotated by the fluid. That is the fluid on the pressure surface will push the blade towards the suction surface and hence we will see that the direction of rotation is from the high-pressure surface to the low-pressure surface. In case of pumps the situation is just the opposite.

We have that in this case the blades drive the fluid and hence we will have the direction of rotation to be reversed. Also please note this arrow nomenclature we are using, we are using a filled arrow for pump P for pump here, it can be pump or compressor and this hollow arrow is for turbine. I will try to keep these arrow symbols as consistent as possible. So to summarise this slide because this slide is very important, I am talking about pressure and suction surfaces and the direction of rotation is dictated by the pressure and suction surfaces and their orientations and as shown in this cartoon.

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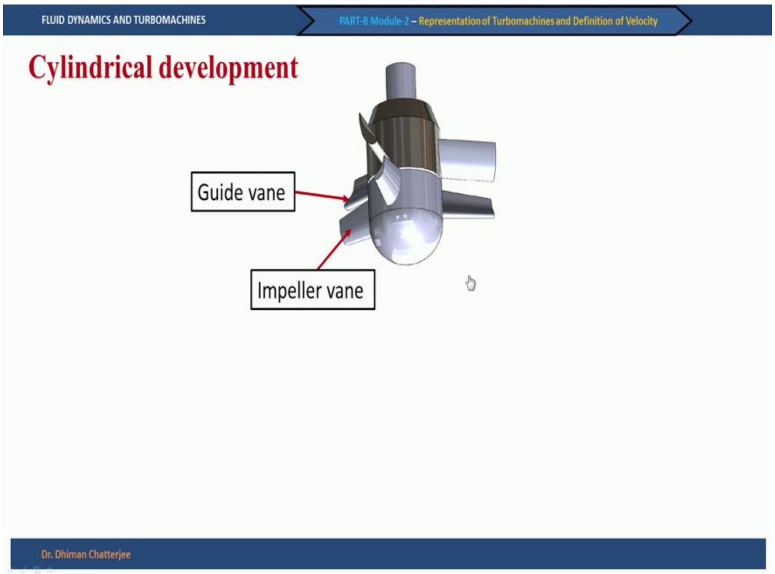

Also you have to note that in case of aerofoil the flow is always takes place where there is a leading edge, the flow is approach always hits the leading edge, the flow can never come from the reverse direction. We have to now understand what is known as cylindrical development. So I get back to a model of an axial flow machine which is now shown. You can see there are 2 sets of blades, the first set of blade is called the guide vane which as you can see is not really connected to the shaft, there is a small hollow gap which is not very clear here.

But there should be a gap, it is a stationary blade or the guide vane and the other set of blade is connected to the hub, it is called the impeller vane. This is a three-dimensional view, so now if I want to take from this view, I want to draw it what is known as cylindrical development, then I have to imagine how to get it.

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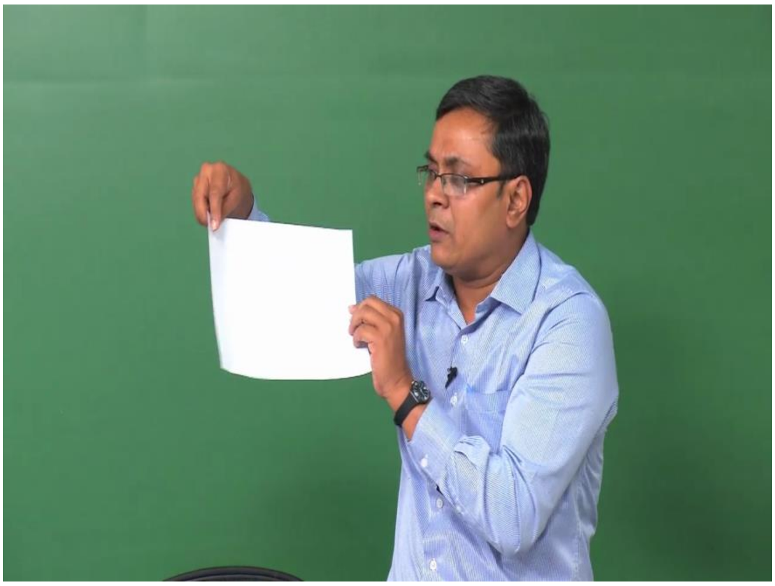

So imagine this is an axial flow machine, just now that what I showed you on the screen. Now if I want to wrap the axial flow machine with a paper, what I do, I take a coaxial cylindrical surface and wrap it around the Turbo machine, around the impeller blades let us say and then these blades will pierce through this paper and we will get hollow. Now if we straight out the paper we will get the positions marked on this paper which are the marks, positions for the blades. I will try to show you the same in this PPT with the help of the solid models that we have created.

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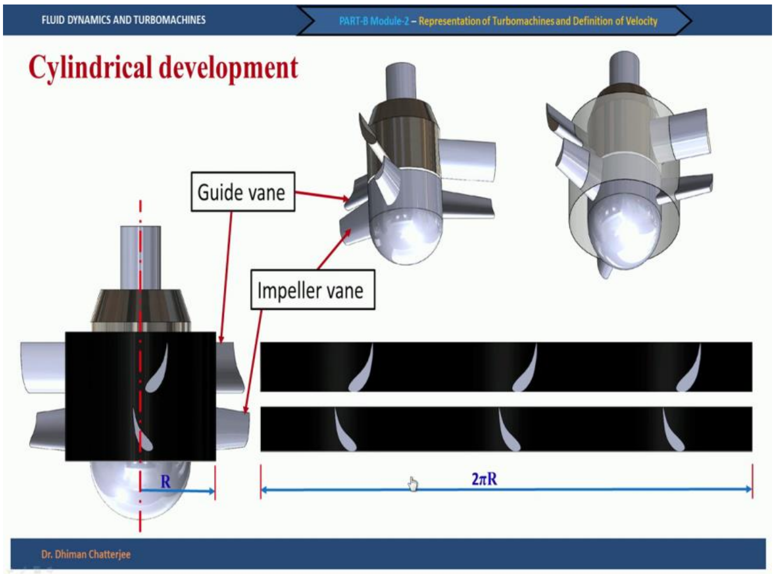

So let us look at it I have put this paper, the circular one and you can see that it pierces through the blades pierce through this paper and both the guide blades as well as the impeller blades, both pierce through the paper. To look at it more closely what has happened is this is a portion of the paper just shown which is wrapping around the axial flow machine and when the blades cut and come out through the paper, this paper will have a shape cutout which is the shape of the aerofoil profile at that radial location.

And when we stretch it out, just as I set the cylindrical development, we get the blades. In this case there are 3 blades, so we get the 3 blades, the bottom blades are the impeller vanes and the top ones are the guide vanes. We will look at it more closely once again.

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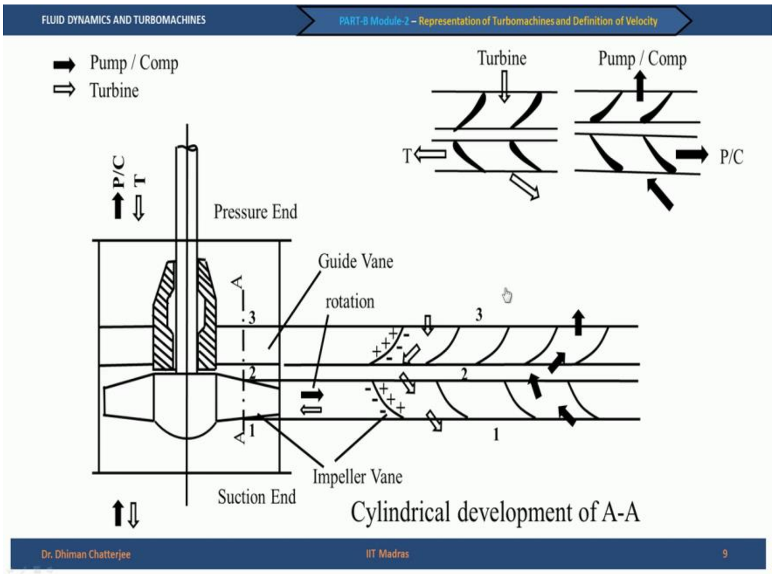

So we are now talking about a unified representation of pump and compressor as well as turbine. Here is the black filled arrows just as I told you earlier represent the pump or the compressors, comp is a short form of compressor. And this hollow arrow is for the turbine. So in case of a pump the fluid flow takes place from the bottom to the top as shown and in case of a turbine the flow takes place from the top to the bottom and we know that the flow should always approach the leading edge or the rounded edge of the aerofoil and hence this aerofoil you can notice has a rounded edge here Aligned in this way and the other aerofoil which is the impeller vane also has a rounded edge.

So even if this I do not give you this arrow, I simply say that this is a turbine blade, then you should know first of all that since there is a rounded leading edge and a sharp trailing edge, the flow must take place from top to bottom. Even if I do not tell you the direction you should be able to say just by looking at the rounded leading edge and the sharp trailing edge. And next if I tell you that this is a turbine, then you know this the pressure surface and this side is the suction surface.

And just as we have discussed the rotation should take place from the pressure surface to the suction surface as shown by this arrow. Had it been a pump the flow takes place from the bottom to the top and you see as expected the leading edge, the rounded leading edge is at the bottom and the sharp trailing edge is at the top, which means that the flow must take place from bottom to top and if you also told that this is a pump or a compressor, you know that the blade actually moves the fluid and the direction of rotation should be reverse of what we expect from the pressure surface to suction surface.

This is the pressure side surface, this is the suction surface, so direction of rotation should be reverse. This is also brought out more clearly by this picture where the pressure surface and the suction surfaces are shown. Do not get confused that 2 blades are showing turbines and some blades are showing pumps, that is because we are showing both the things in the same view. Also you note that this aerofoil can be represented by a camber line and this line simply represents the aerofoil where they are showing only the camber line.

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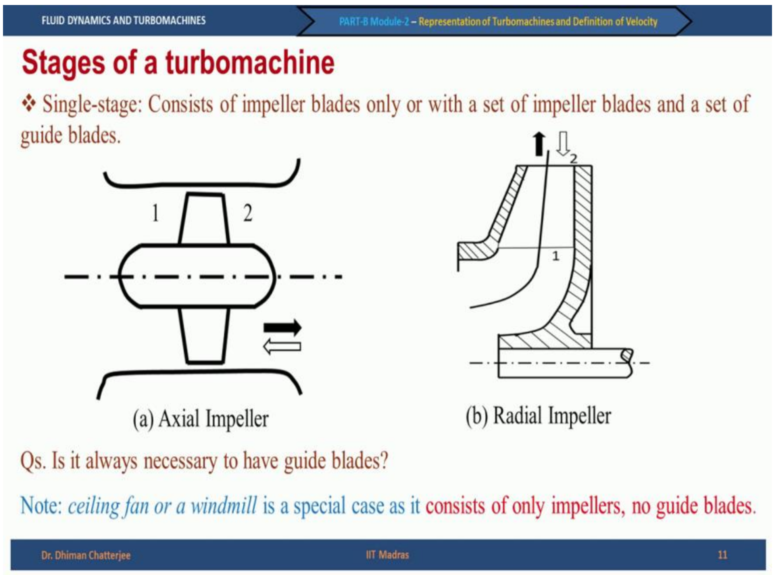

The thickness distribution around the camber line is not shown, I will explain this point again shortly. So this is the guide vane and these are the impeller vanes. Now we will talk about stages of a Turbo machine. So by stages of a Turbo machine we say that the Turbo machine can be of single stage or multiple stages. For example when you saw an axial flow compressor which we showed you in the last week we talked about the many stages, there are many sets of the guide vanes or the stationary blades and the rotating blades or the impellers.

We have also another axial flow machine, the Kaplan turbine where there was only one set of rotating blades. So we can talk about stages of a Turbo machine as a single stage which consists of impeller blades only or with a set of impeller blades and a set of guide blades. Let us look at these pictures. So this is an axial flow machine in which you can see you can easily see that if we join a line 1 to 2, the flow direction is parallel to the axis, it is an axial flow machine because this is a rotor or a impeller vane and this is a radial flow machine.

So you go from 1 to 2, you see that the angle is 90 degrees. And you can also notice the flow direction in case of a pump and in case of a turbine. For example the black arrow shows the, filled arrow shows the pump and the other one for a turbine. So in case of a pump the fluid flow goes from a lower radius to a higher radius, in case of a turbine it is just the reverse, it comes from a higher radius to a lower radius. The reason for this also will become clear in the next lecture.

So is it always necessary that we should have guide blades, the answer is no and we all know from our common experience of ceiling fans or the windmill that there are only impeller blades, there are only runners and there are no guide blades. Next time when you look at the ceiling fan you should see that the blades rotating and you should call them as impellers or the rotors or the runner blades.

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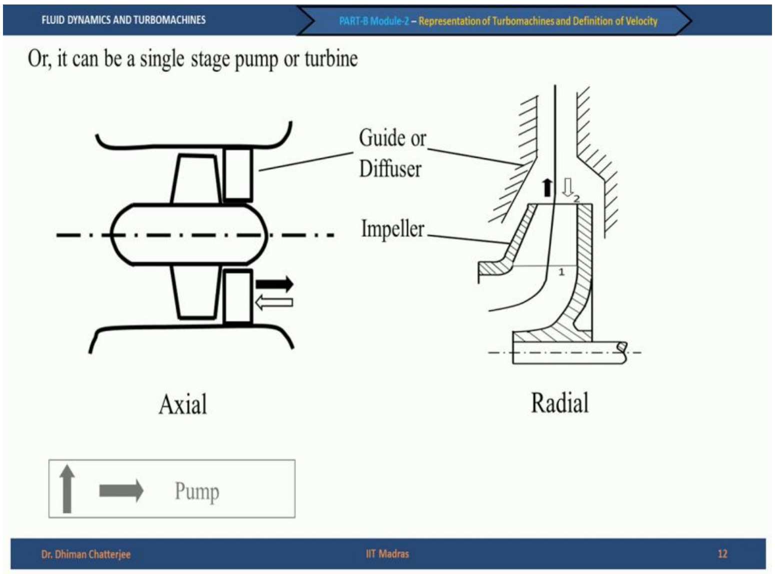

We can also have a situation where a single stage pump or a turbine as shown here for both axial and radial will have guide blades or diffusers and we can have this situation also possible. That is you can have scenarios when there are no guide blades, no stationary components or you can also have the guide blades or stators or stationary blades.

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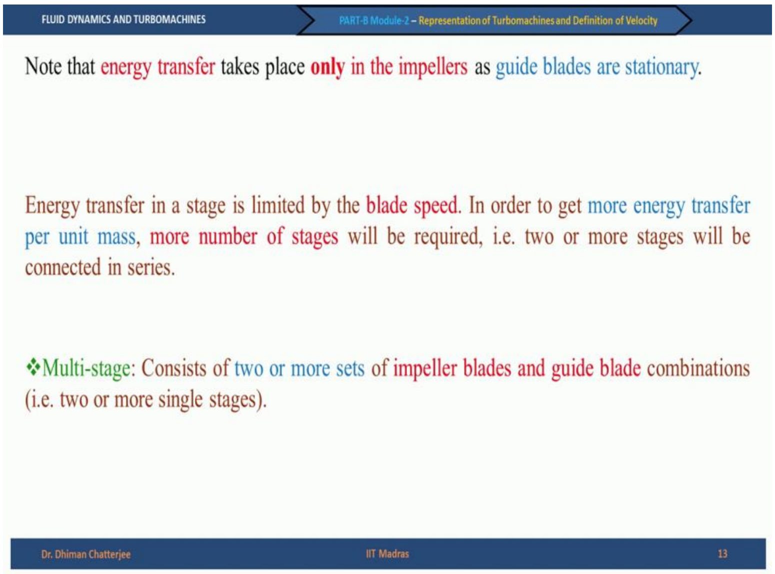

The next category is that when we talk about it, we are talking about 2 types of blades, the guide blades and the impellers. The guide blades or the stationary blades are fixed, there is no energy transfer that takes place and hence the energy transfer takes place only in the impellers. Energy transferred in the stage is limited by the blade speed, we will see this when we talk about the Euler's energy equation in the next class. In order to get more energy transferred per unit mass, more number of stages will be required.

That is we may not just be restricted with one stage, we may need more stages. I will come to the number of stages or multi-staging soon. So multi-staging means it consists of 2 or more sets of impeller blades and guide blades combinations, that is we will have replica of single stages stacked on the same shaft.

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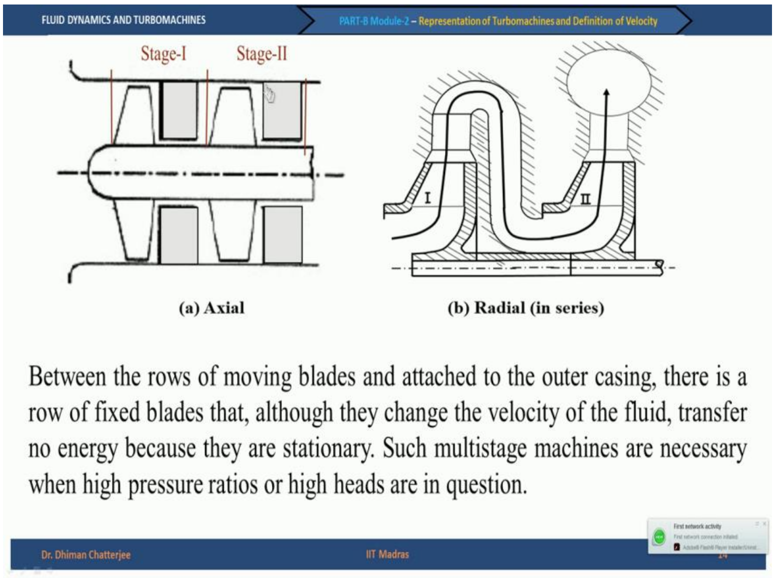

Please note the picture here carefully. We have 1 rotating blade and 1 stationary blade and this picture is repeated here with another rotating blade and a stationary blade for this axial flow machine. So this is called the stage 1 and the next one is called the stage 2. In case of a radial flow pump for example the flow goes from a smaller radius to a larger radius, then there are diffusion processes in the stationary component and then it is fed back to the 2^{nd} impeller and then it goes out. So these both are examples of 2 stage Turbo machines.

Also you have to remember, let us say what is the difference between the 2 stage pump and a 2 pumps in series. You can think of this in this fashion. That in case of 2 pumps they have independent controls, they have independent shafts connected to Independent motors. So now motor from one pump can enter the 2^{nd} pump and can rise. This is a common scenario if you have a very high-rise building. You can say for example that from the ground floor I will take it to an intermediate reservoir in a let us say 5^{th} floor and from 5^{th} floor I will take it by another pump to the 10^{th} floor.

But we are not talking about that scenario here. In this case both the impellers are connected to the same shaft and driven by the same motor. So we are talking about the same shaft, same housing holding both stages 1 and 2. And of course you can see that between the rows of moving blades and attached to the outer casing, there could be rows of fixed blades. So such multistage machines are necessary when high pressure ratios or high heads are in question.

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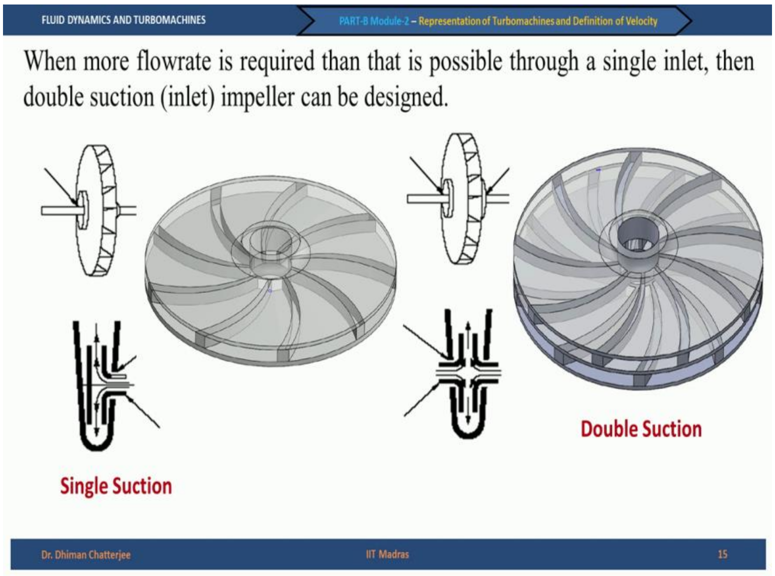

When more flow rate is required, what should we do? We cannot the staging because in case of staging as you have noted the fluid, same fluid goes from one impeller to another impeller, from one stage to another stage, there is the possibility of increase of flow rate. The way of increasing flow rate if we require more than what can be coming through a single inlet is to have double inlet, these are called the double suction impellers. So this is a picture which we have shown you of a of an impeller and the corresponding views are shown here.

You see that the fluid enters from one side and then goes through the impeller and is collected by the remaining component of the pump which we are not interested at this stage. That is there is only one entry of the fluid is a single suction impeller. Now, when I want more fluid, I cannot possibly take it through the single inlet, then what I need to do is I need to perhaps sometimes it is required that I will put 2 impellers, you can see like 2 tiers of impellers, one at the top, one at the bottom, so the fluid in this case can enter from both sides.

See the fluid can enter from the left and go as well as from the right. So the fluid enters from the left and the right and then it is collected. And this is known as a double suction impeller. This is very important, for a single suction impeller the fluid comes from the left and goes to the impeller and is collected by a collector, we will call it a casing. In case of a double suction impeller the impellers are on the stack on the both sides and the fluid flow enters from both sides and is collected by the casing.

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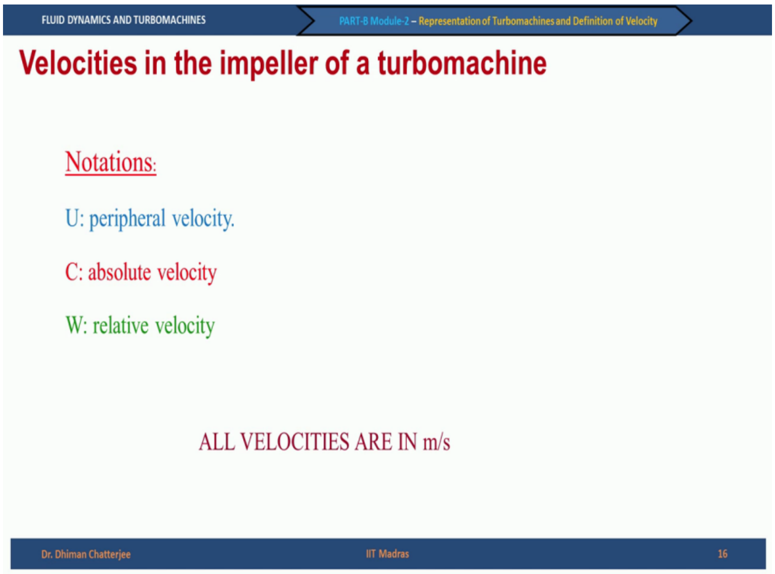

So we can actually double the flow rate. So next thing is that when we are talking about the flow, we need to talk about velocities in the impeller of a Turbo machine. When we talk about the velocities in the impeller comfortable machine, we need to keep in mind the following notations that we are going to use. 3 velocities come to our mind, the first one is the blade peripheral velocity which is given by capital U, 2nd is the absolute velocity which is given by capital C and the 3rd is the relative velocity which is given by capital W.

It is needless to say perhaps to you that the notations are not uniform across books, what I have followed is a consistent notation of U, C and W. So whenever you see incoming slides I have used U, I have used C or W, you should know that these mean peripheral or absolute or relative velocity. So let us see how these velocities and of course we will use for the problems in tutorials these velocities are in metre per second, we will not use any other units.

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So relative velocity and the path of a particle inside the blade passage. Let us look at the model impeller once again. So this is the model impeller and this model impeller is going to rotate. If it is rotating like this, you can see the blades rotating about this axis, then what happens, if I have a fluid particle here, this fluid particle will travel from the smaller radius to the outer radius, ideally along the blades and also if I, that is if I am sitting on these vanes and try to look at the blade any one fluid particle, then I will see that the particle has started its journey from here and move to the outer edge.

Whereas if you are sitting on in the laboratory and trying to trace the particle, what you will see is my hand is moving and the particle is also moving. This is now brought out with the help of a movie in the slides.

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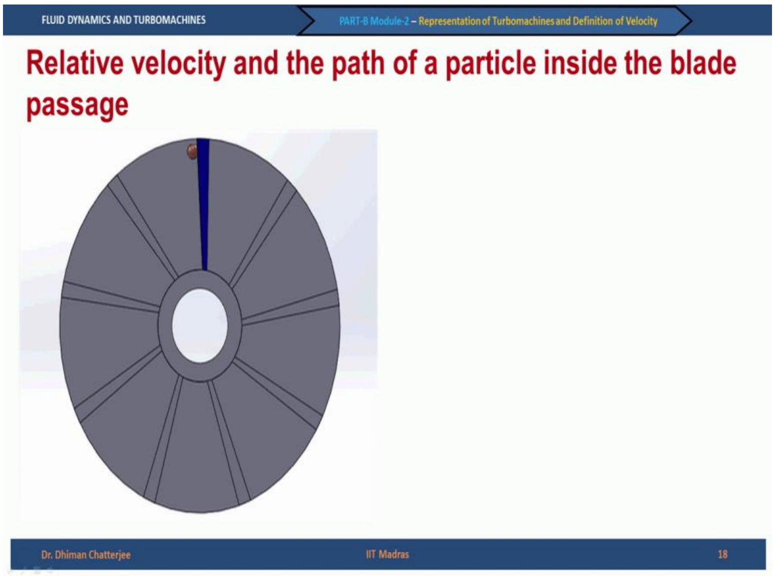

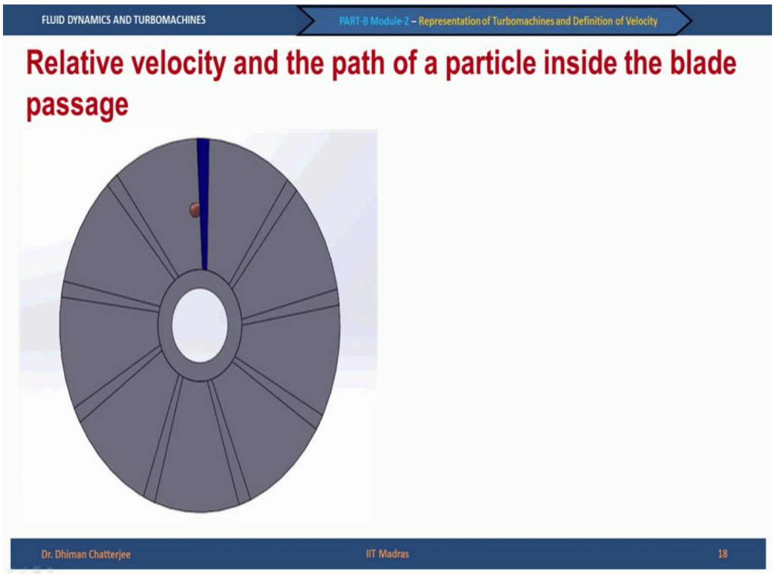

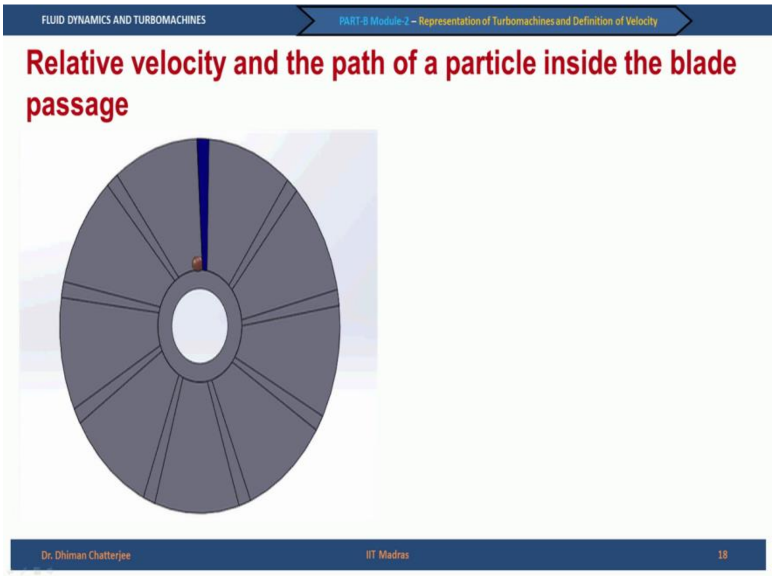

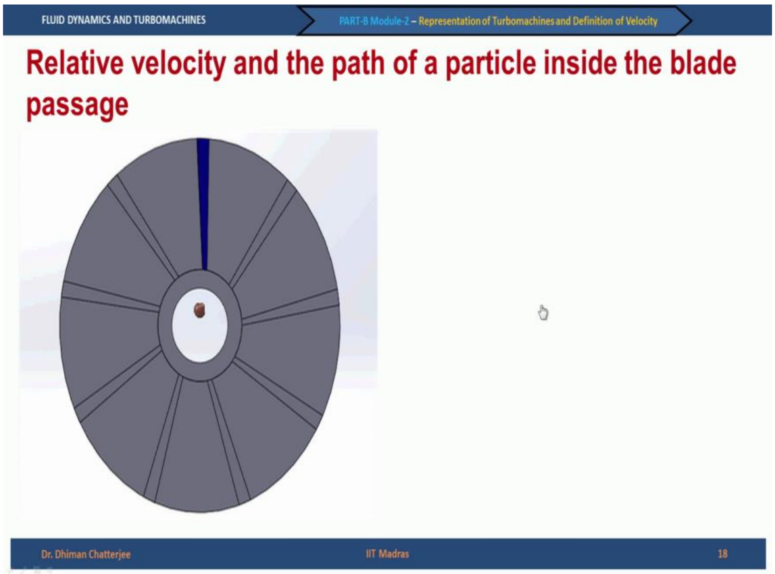

Let us look at an impeller and one of the blades have been just marked as blue, so in this left side what we are showing, you imagine that you are sitting on this blade and that ball which is shown is a fluid particle which is at the inlet edge, the ball is located at these outer diameter and the blade is going to rotate. But do not forget that you are sitting on this blade. Then what you will see with respect to the blade what is the position of the fluid particle with time? That is the relative position of the fluid particle with respect to the blade.

I repeat the animation once again you see that as the blade rotates, the particle is moving inward and leaves through the smaller or inner diameter. This is what you will visualize when were the blade. Now if you are sitting in a laboratory and watching the same motion, then look at it what we see.

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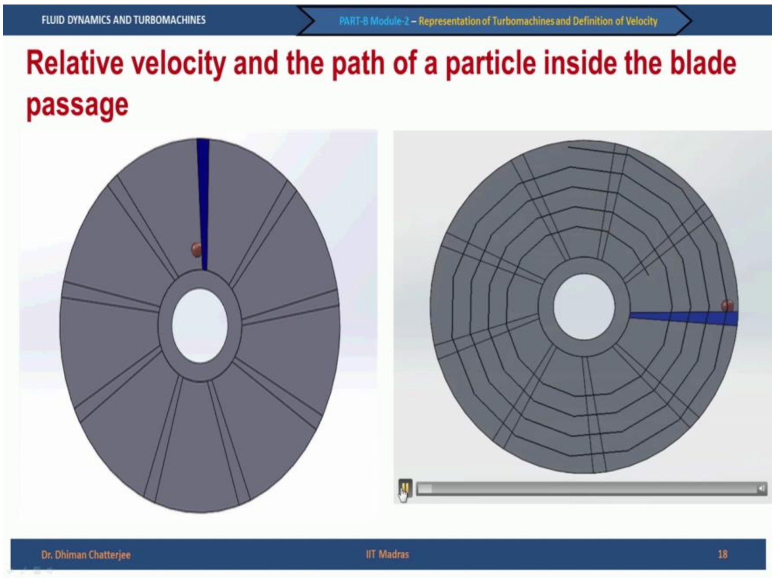
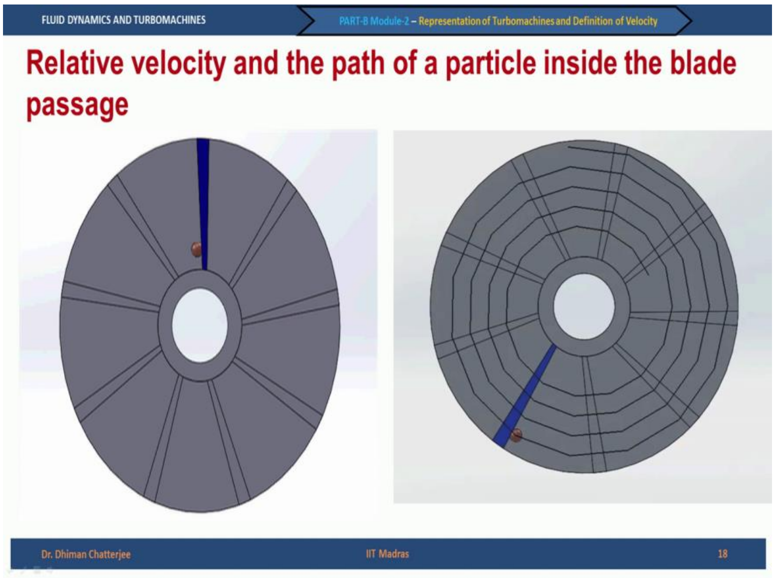
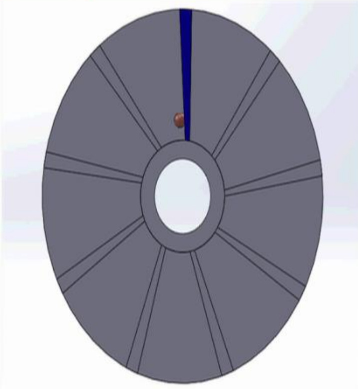
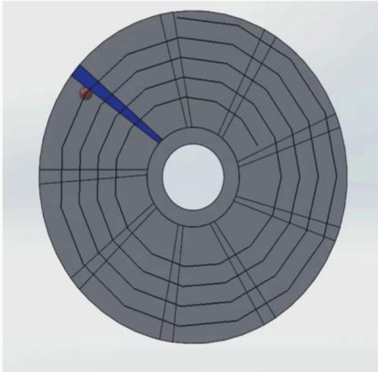


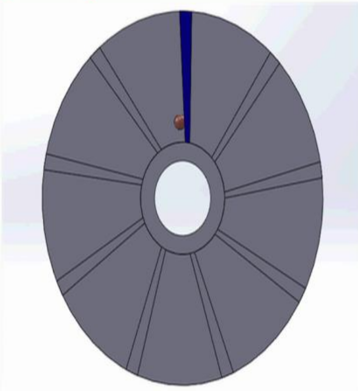
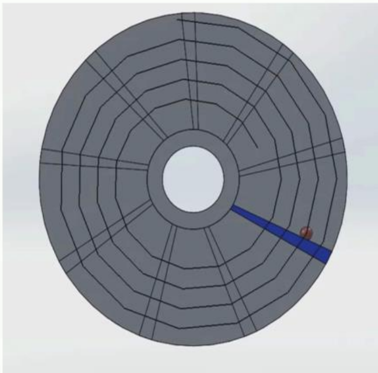


Relative velocity and the path of a particle inside the blade passage

FLUID DYNAMICS AND TURBOMACHINES
PART-B Module-2 – Representation of Turbomachines and Definition of Velocity

Relative velocity and the path of a particle inside the blade passage

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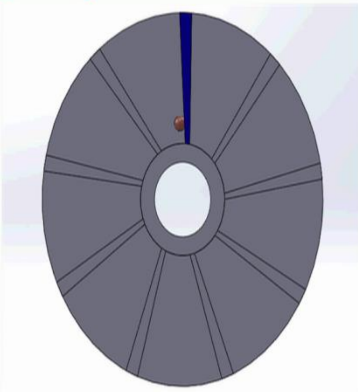
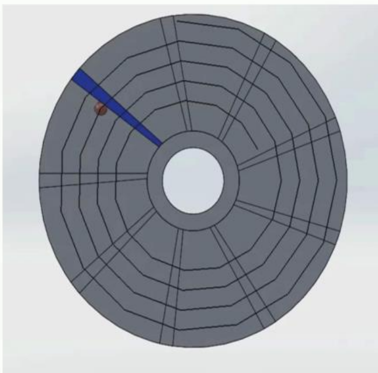

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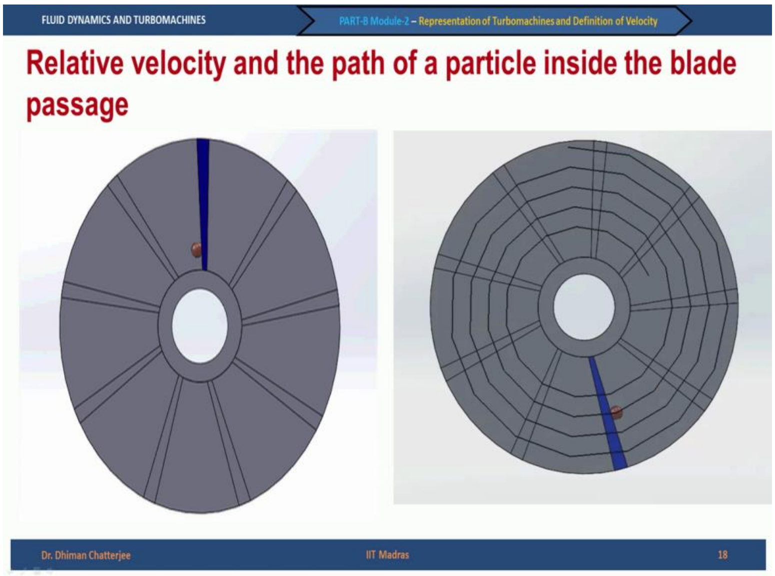

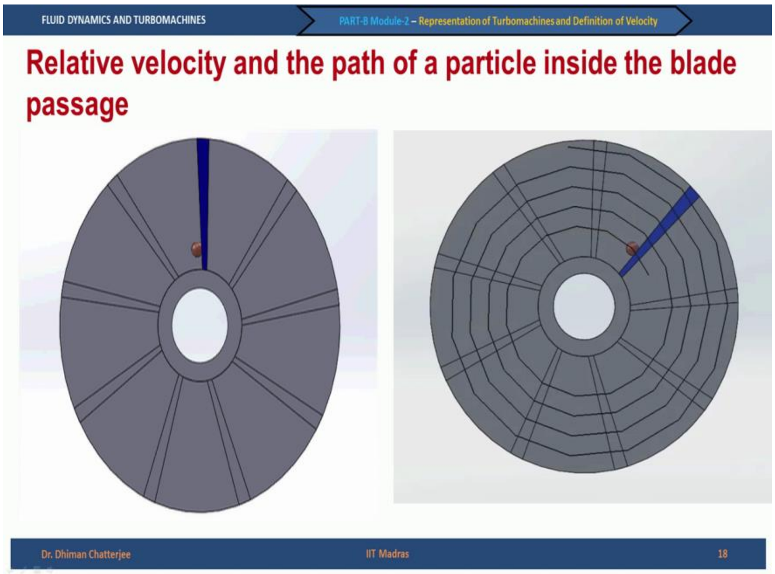

The particle starts from the same outer diameter location and the blade is rotating in the same direction, however this time you are not sitting on the blade, you are sitting in the laboratory and watching the blade rotate. So let us look at this. So you see the particle is moving in inward but it is also moving in whole 360 degrees and the path that is being traced out is known as the absolute path of the particle that the particle will follow. It is a spiral in nature. So you see again very carefully that from the outer edge diameter it comes to the inner diameter and it traces out these paths, this path is known as the absolute path for the fluid particle.

Thus we have to be very clear when we talk about velocities inside a Turbo machine inside the rotating blades about the relative velocity and the absolute velocity. And the connection between the 2 is because of the vector relationships connecting the relative velocity, the absolute velocity and the blade peripheral velocity, we will see that soon.

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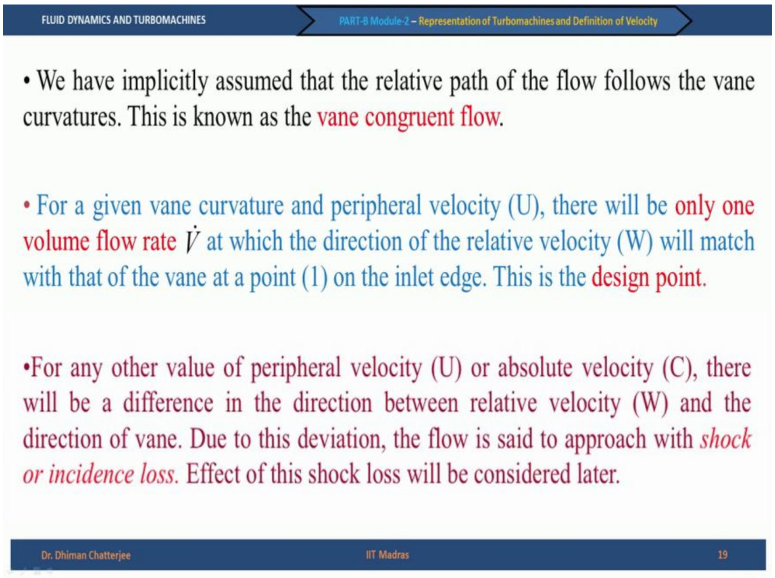

In these animations, in these cartoons we have implicitly assumed that the relative path of the flow follows the vane curvature. This is known as vane congruent flow. In reality of course there could be deviations from the vane curvature path but we will take it up in a latter course of the lecture. So right now I assume that the particles follow the vane curvature and which is known as the vane congruent flow. For a given vane and peripheral velocity U, there will be only one volume flow rate V dot at which the direction of the relative velocity W will match with that of the vane at point 1 on the inlet edge.

This is the design condition. We are talking about a particular flow rate at which this flow will enter and leave tangentially to the blade. And for any other velocities or any other rotational speeds, this will not be the case and the flow will enter and leave at angles which are different from the blade curvature angles. This will give rise to additional losses which are called shock or incidence loss, I will talk about these additional effect of the shock loss on the performance of Turbo machines later on.

But right now having said that there are possibilities of deviation from the vane curvature congruent flows, I will still talk about the vane congruent flow because that gives us insight to the Turbo machines.

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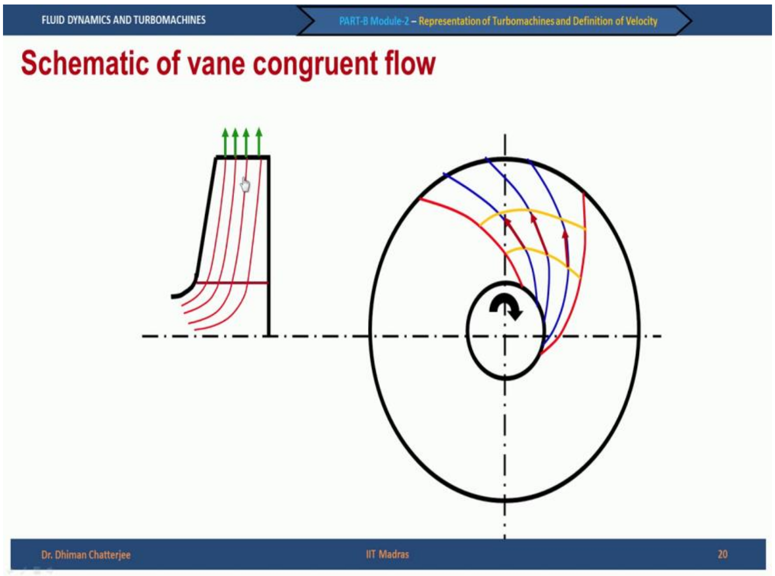

So schematic of a vane congruent flow. When I say that the fluid follows the vane curvature, I mean there is no Theta dependency, if Theta is the azimuthal angle, there is no Theta dependence and so if I draw the velocity vectors at each point on the lower circles, so you will see the magnitude the same, so you will get a uniform portion. And this is also shown in the Meridional view of the impeller.

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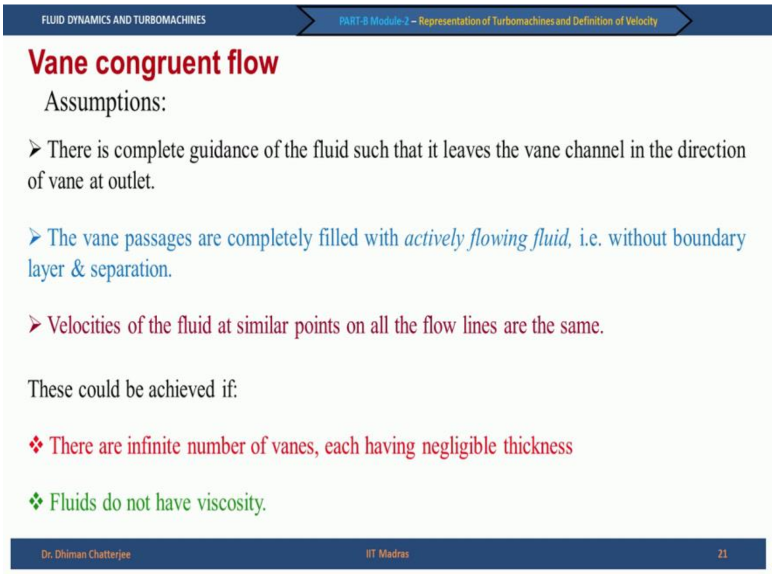

So what are the assumptions under which this idealised condition can be realised, we say that there is a complete guidance of the fluid, please note the word complete guidance, I will explain it now, of the fluid such that it leaves the vane channel in the direction of the vane at the outlet. 2 things are important here, first, we are going to do the analysis of Turbo machines by considering only the information available at the inlet and the information available at the outlet of the impeller. We are not going to trace the velocities or find out the velocities at any intermediate location.

So any deviation that takes place, we will lump it at the outlet edge and hence when I say complete guidance, I mean that these such effects are not present and we will get the vane channel in the direction of the vane at the outlet. The vane passages are completely filled with actively flowing fluid that is without boundary layer and separation. Velocities of the fluid at points similar points on all the flow lines are same. This we have already shown schematically in the last figure. And this would be achieved if there are infinite number of vanes each having negligible thickness and fluids do not have viscosity.

What is the significance of the first point, that is there are infinite number of vanes? Imagine that you are taking some nursery kindergarten children to the zoo and now you enter the zoo with these kids and you are taking them around. If there are only 3 of you friends who are guiding these students, these kids, then what will happen, the kids will try to go out of their curiosity to different places, they may not follow the path that you would like to follow. But now you imagine that you are large number of friends who are standing from the entrance to the cage of the animal all along the path.

So at every point you ensure that the kid follows the line you have drawn for the kids to follow. So now what it means is that if you have enough guidance, then only the kids follow the line, otherwise because of the nature of curiosity they will try to go in a deviated path. Similarly for the fluid if I want to direct the flow in a particular passage, then I have to say that the number of vanes should be such it is infinite that it directs the flow.

But there is a problem if the number of vanes are infinite, what is the problem? The infinite number of vanes or a large number of vanes for that matter will have, each will have some thickness and then the total thickness which will occupy the flow passage and will not be insignificant. So this idealisation is achieved when we talk about infinite number of vanes each having negligible thickness. And if fluids do not have viscosity, then we do not have to worry about boundary layer and separations and so the wall effects are not present, the separation which can happen in the flow passage is also neglected and hence vane congruent flow assumptions will be valid.

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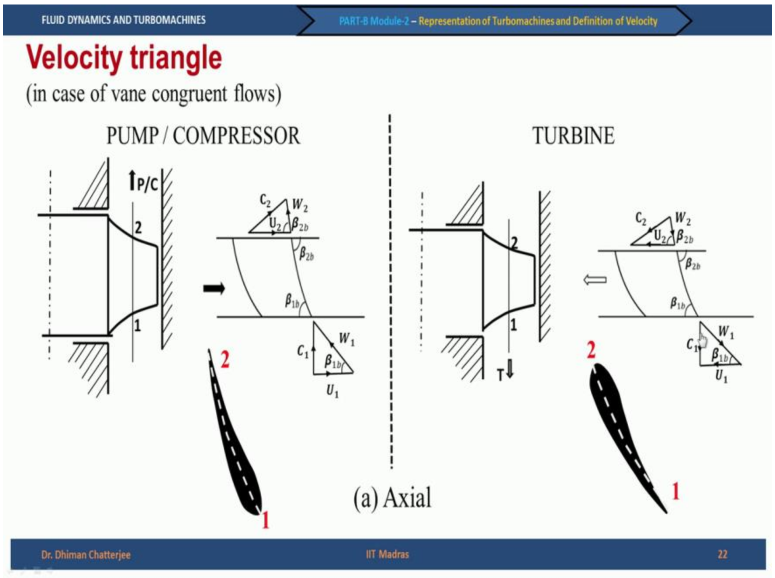

So we will talk about the velocity triangle in case of vane congruent flows. We will start with axial flow Turbo machines. So first we talk about pumps and compressors. So first we are talking about pumps and compressors, and as we have shown earlier this is an axial flow machine, you can see that is the line joining 1 to 2 is parallel to the axis and the flow in case of pump or compressor is from bottom to top.

So we see that in case of pump the flow is from bottom to top and we know that in the direction of the flow in case of pump the pressure increases and hence the outlet of the pump is that a higher pressure than the inlet and we put the outlet at 2 and inlet at 1. And if we take a section of the blade along this line, we see it is an aerofoil and has a rounded leading edge at 1 and a sharp trailing edge at 2. This white line is called the camber and this camber is now represented in this picture.

So you see the flow is tangentially entering, when I say the flow is entering tangentially to a rotating blade which is the velocity which should be tangential? It should be of course the relative velocity. So you see the relative velocity is tangentially entering the blade passage and leaving the blade passage again tangentially. That is the flow angles beta 1 and the blade angle beta 1B or beta 2 and beta 2B should be identical. I will talk about these angles later.

We also know that this is a pressure surface, this is a suction surface, so in case of pump the direction of rotation is from left to right. And hence U1 or U2 are given as left to right and this is the absolute velocity. In case of turbine what happens? We have the similar axial flow Turbo machine but in this case the flow is from top to bottom, inlet of the turbine is at a higher pressure, we have given the notation 2, outlet of the turbine is that a lower pressure, we give it 1 and we see that it is from 2 to 1.

Here you should not make a mistake of putting 1 to 2 because 2 is at a higher pressure at the turbine inlet. This is the crux of the unified notation of pumps and turbines. You see here in the left-hand sidethe pump outlet is at 2 signifying higher pressure and the turbine inlet is at 2 signifying higher pressure. So here again the camber is shown. Now this is the positive surface or the pressure surface and this is the suction surface and the direction of rotation should be from right to left as indicated. Here again you can see that the fluid enters tangentially to the blade and leaves also tangentially.

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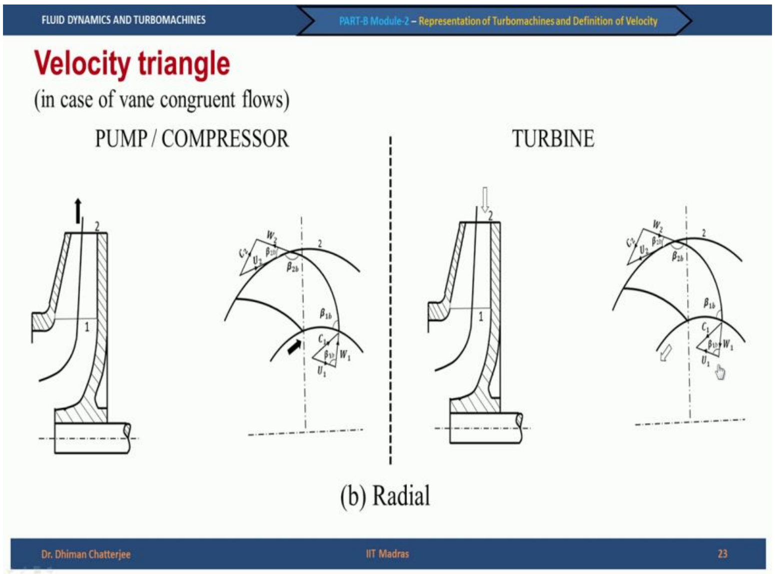

In case radial flow machines, the similar pictures can be drawn. This is a direction of rotation but as you have noticed in case of radial flow machines we may not use an aerofoil structures, aerofoil cross-sections, we may use simply blades which are bend, because that is economical and it serves purposes, you may need to fillet it to get a roundedness. So in this case, in case of pump or compressor the flow is from a smaller radius to a larger radius, you may be wondering why not in the other direction, I will talk about it soon.

So what happens is that when we talk about this 1 and 2, we say that the flow enters at a lower pressure, that is why the notation subscript is 1, leave at a higher pressure, subscript is 2 and the flow enters tangentially, which means that W 1 is tangent to the blade at the inlet and W 2 at the exit. The reverse scenario in case of turbine. And you see that the fluid enters tangentially to the at the inlet which is at the outer diameter and leaves tangentially at the outlet which is at the inner diameter and direction of rotation is also shown.

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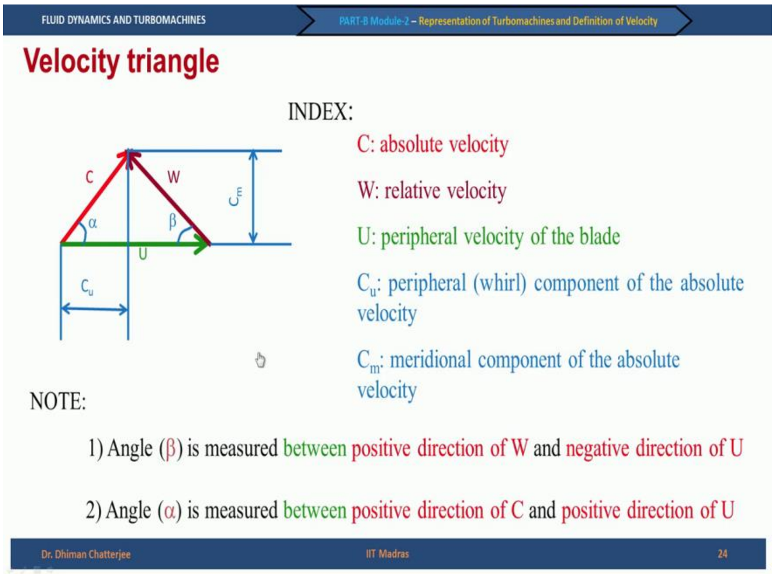

Now direction of rotation in case of radial flow machines is not obvious, we will talk about it when we take up the discussion of effect of Blade curvature later on. So to sum up the velocity triangles and this is the notation we will follow. One of the observation that I have made is about these angles beta, I have talked about the absolute velocity C and the relative velocity W. I have shown as that beta is the direction which is, angle which is made between W and U and please note that U is the blade peripheral velocity which means it is the tangential of the blade. But if you come across different Turbo machine books you will see that different notations are followed.

But for these lectures I will follow the consistent notations of alpha and beta as shown here. Okay, I once again want to repeat that C is the absolute velocity, W is the relative velocity, U is the blade peripheral velocity which is in the tangential direction, CU is called the peripheral or the whirl component of the of the absolute velocity, you see I have taken a projection, this is CU, this is essentially the tangential component of the absolute velocity and Cm which is shown here is called the Meridional component of the upfront velocity.

Now Cm or the Meridional component of the absolute velocity may mean different things for radial flow machine and for axial flow machine. For axial flow machine, it will be the axial component and for a radial flow machine, it will be the radial component., Because in the Meridional view what you can see is the axial motion or the radial motion in the 2 cases. So please note that C while CU represents the peripheral or the tangential or the whirl component of the absolute velocity, the Meridional component, the subscript m for Meridional may mean, in the case of radial flow machines, the radial component and in case of axial flow machines the axial component.

The angle alpha and beta needs to be considered in a careful way. So they say that in these lectures we will take angle beta which is measured between the positive direction of W, you take this, this is the positive direction of W and the negative direction of U. These are all vectors, so the arrow shows the positive direction and the reverse will be the negative direction. So beta is the angle which is measured between the positive direction of W and the negative direction of U.

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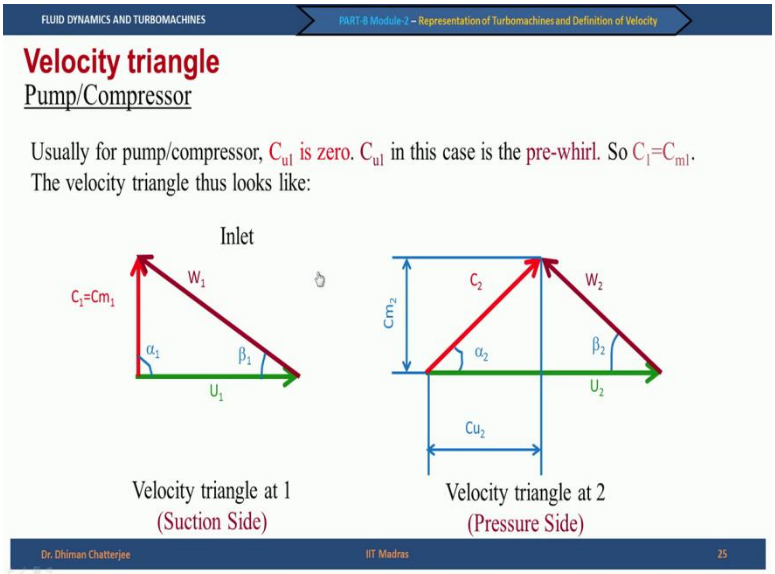

Whereas alpha is the angle which is measured between positive direction of C as well as the positive direction of U. We will follow this sign convention and the notations consistently for these lectures. We can have for the pumps or compressors CU 1 to be zero, CU 1 in this case is the pre-whirl, which means that C1 equal to Cm1 and the velocity triangle will look like this. This is not necessary that always the inlet whirl component of absolute velocity will be zero but many times, at least for the design purpose we take this component to be zero and in that case you see that C1 equal to Cm 1 and alpha 1 equal to 90 degree and in case of outlet of course we have the usual part.

We have alpha 2 not equal to 90 degree, it is not possible. In case of turbines we can say that same thing, we can say that CU 1 can be assumed to be zero, it is again need not be always the case but many times while designing a turbine we can consider it to be zero in the first case but there are examples or there are requirements when CU 1 you did not take it to be zero as well.

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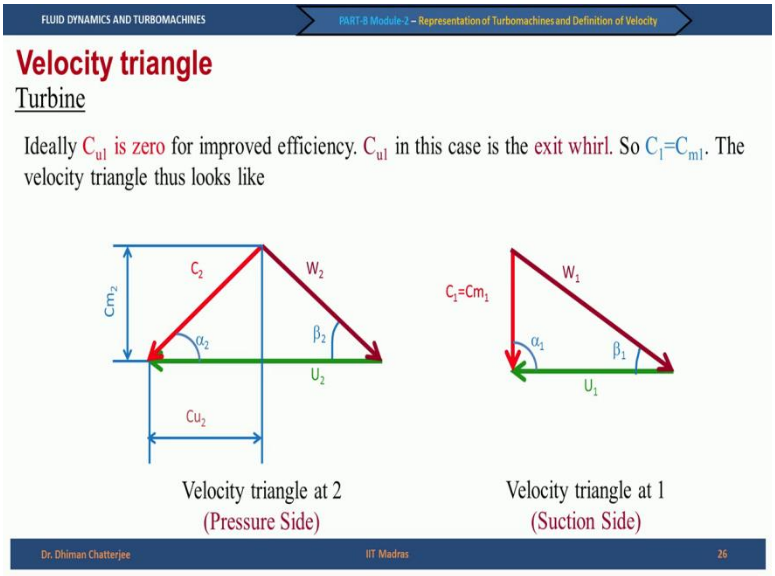

But if we assume CU1 to be zero, then what we get is that at the exit side we will have or the suction side we will have alpha 1 to be 90 degree and this is the pressure side. Now I think the advantage of using the uniform notations of 2 and 1 is apparent. If you look at the velocity triangles shown for turbine, what are we saying, were saying exit whirl is zero, so what happens, CU 1, 1 being the exit side is equal to 0. If you look in the previous slide once again for the pumps or compressors, we said inlet whirl is zero.

What do you get, CU 1 is again zero. So you see if we remember what is inlet whirl, what is exit whirl, then if we do the formulation, all it means is CU 1 is zero. Do you get the point? That CU 1 is zero irrespective of whether it is pump or turbine, that is whether it is an inlet whirl or pre-whirl or the exit whirl, this is very important. And that this I believe is one of the major motivations for us to be considering these unified notations for the pumps and turbines. This advantage will become clearer when we take up in the next lecture Euler’s energy equation.

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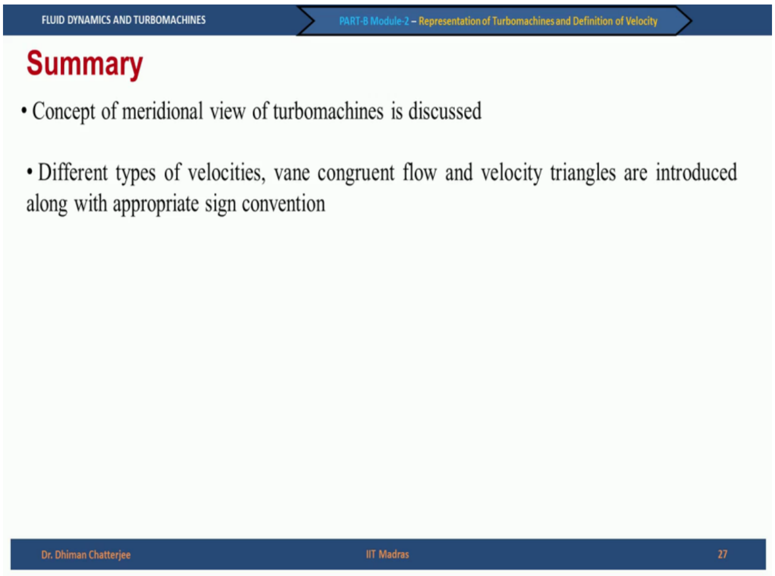

So to summarise what we have learned today, we have discussed the concept of Meridional view of Turbo machines, we have also talked about the different types of velocities, in particular we have talked about the vane congruent flow which form the basis of any introduction to the velocity triangles inside the Turbo machine impellers and we have also talked about the appropriate conventions for the angles. In the next lecture of this week we will talk about Euler's energy equation, that is we have learnt the velocities, we will see how we can apply these velocities and the velocity triangles to derive what is the energy transfer from the fluid to the blade or vice versa. For that I request all of you to revise the lectures given by Dr Bakshi on the angular momentum conservation equation because that will be one of our first starting points for the next lecture, thank you.