Fluid Dynamics And Turbo Machines.
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Part A.
Module-2.
Lecture-2.
Turbomachines: Definition and Classification.

Good afternoon, I welcome you all for today's lecture on Turbo machines definition and classification. In the last class we have discussed about thermodynamics and how it can be applied for Turbo machines. In that we have noted that the Turbo machine internal details were not considered. Today we will start with fluid machines, talk about Turbo machines, little bit of construction and more importantly the classification. So what are fluid machines? Fluid machines involves the application of fluid mechanics and thermodynamics, it also involves conversion of energy from the fluid into the mechanical energy and vice versa.

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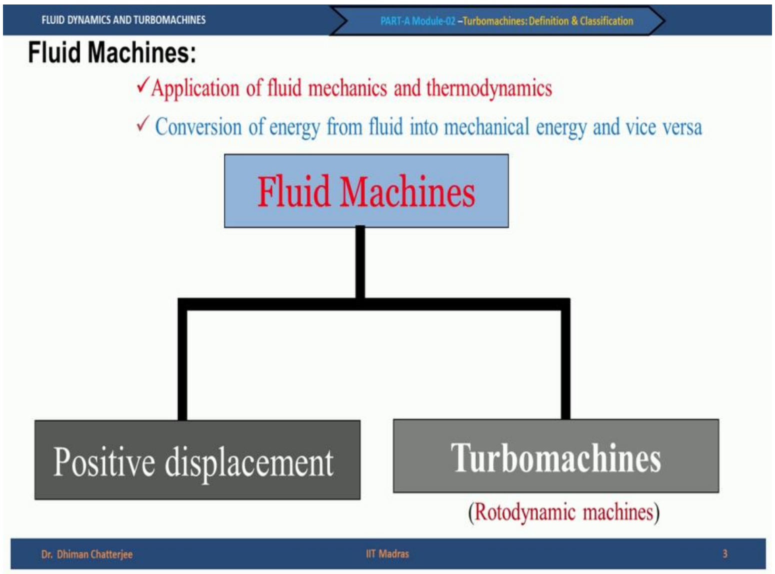

So fluid machines can be broadly classified into 2 categories, the positive displacement machines and the Turbo machines, often called the rotodynamic machines. Though our importance and stress is on Turbo machines, I would like to start with positive displacement machines. I will talk about features of positive displacement machine which are essentially different from that of Turbo machines. And from that we will try to draw the requirements of Turbo machines.

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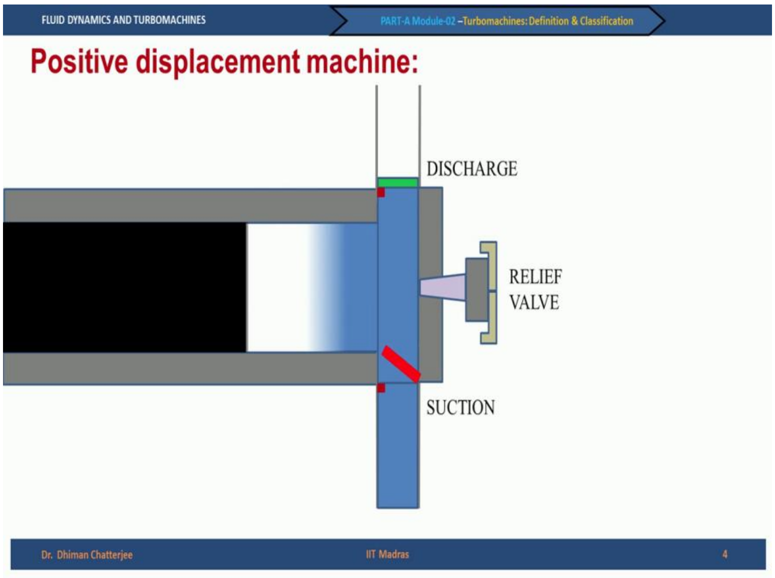

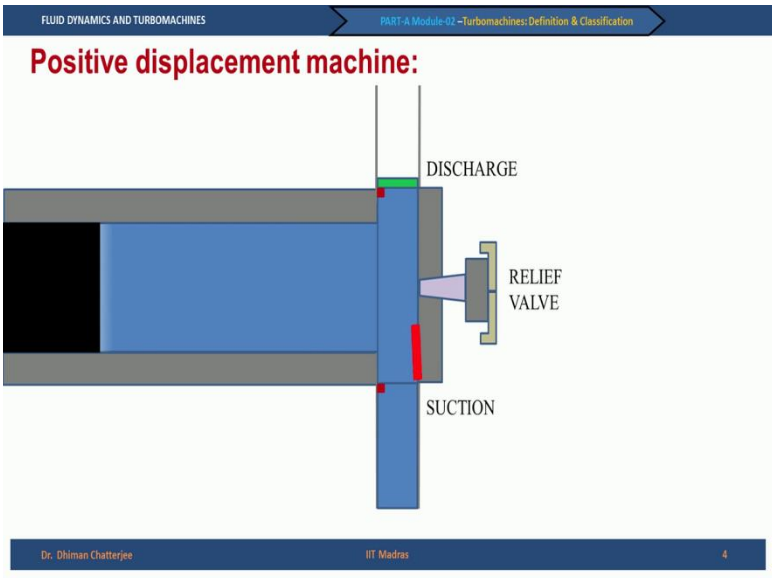

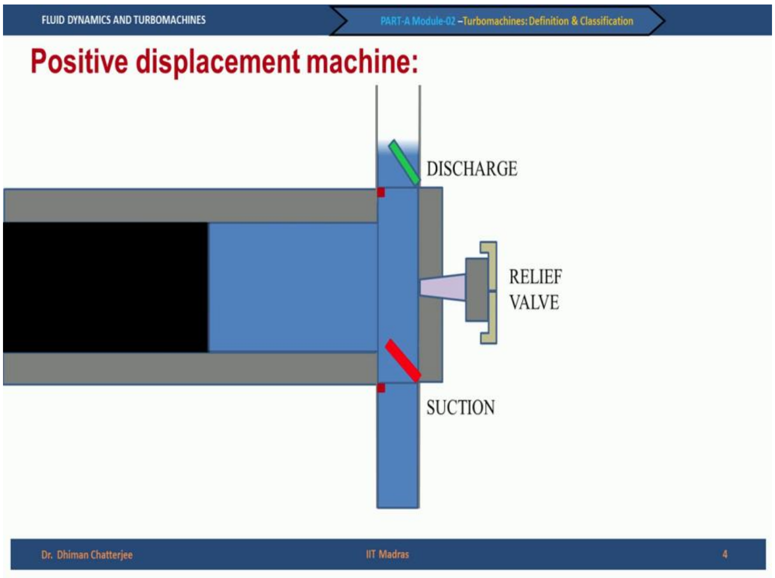

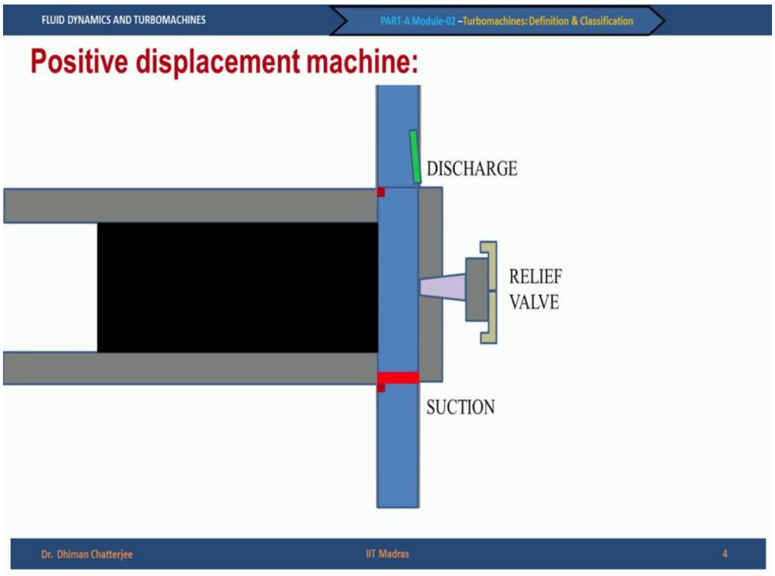

So let us start with the simplest type of positive displacement machine which is called the reciprocating pump. So let us look at the animation once again and we can see that the fluid enters as the valve opens, as the piston goes back and once the piston comes forward, again the fluid is injected out. So we can see there are 2 modes of operation, the first mode is called the suction mode.

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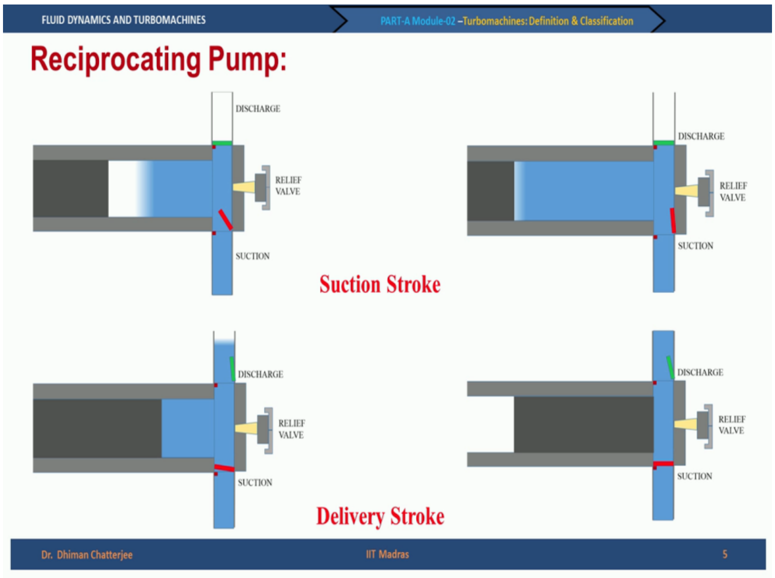

In the suction mode we are showing you 2 instances when the valve is open, why is it opening, because the piston has moved backwards and there is a low pressure inside the cylinder and hence the liquid enters from the suction side, lifts the valve open and enter the cylinder. This process is completed as shown in the right-hand side image. Once the piston starts coming back, what we see is the piston is now pushing from my left to the right and hence the pressure increases, as a result the valve in the suction side closest, whereas the valve in the delivery side opens up and hence the liquid flows out from the discharge side.

And this shows the other extreme on the right-hand side. So this is known as the delivery stroke. So in one cycle the pump will perform one suction stroke and one delivery stroke. So you can understand if there is a suction stroke when the fluid is admitted into the cylinder and there is a distinct delivery stroke in which the fluid is released or discharged to the downstream side, that means the flow can never be continuous. The other thing that we have to keep in mind is that because of the presence of these stoppers which allows only the restricted movement of the valves, there is less chance of leakage.

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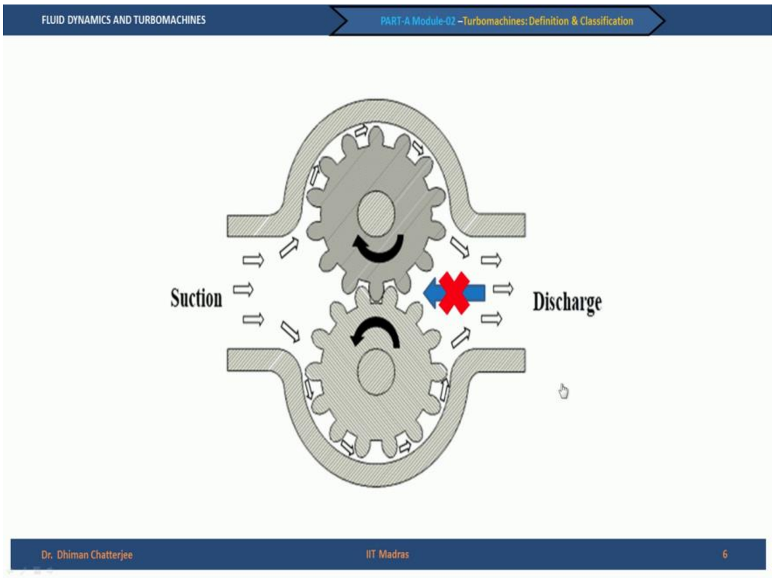

And hence this type of pump is expected to handle higher pressure rise. This makes a very big distinction from that of Turbo machines. But we should not have an idea that the positive displacement machines are always reciprocating. Here there is an example of a gear pump in which one of the gears is our driving gear and the another one is the driven gear. The left-hand side, there is a fluid suction, the flow enters and as the gear rotates the fluid is taken as shown in the arrows on top and bottom to the discharge side. But there is no through flow possible from the left to the right or from the right to the left because when the gear teeth get engaged, there is no passage of flow of water.

So in this case we see first there is no valve, unlike the reciprocating pump, however there is a physical barrier to the flow, to the leakage flow and hence we can say that either a valve or a leakage or a physical barrier is very important to prevent the leakage flow in case of positive displacement machines. Also we have to note that in this case the gears are rotating, in the case of the reciprocating pumps, the cylinder is fixed and the piston is rotating inside. So we see that there is a relative motion in this case between the gear and the casing and in the other case between the cylinder and the piston.

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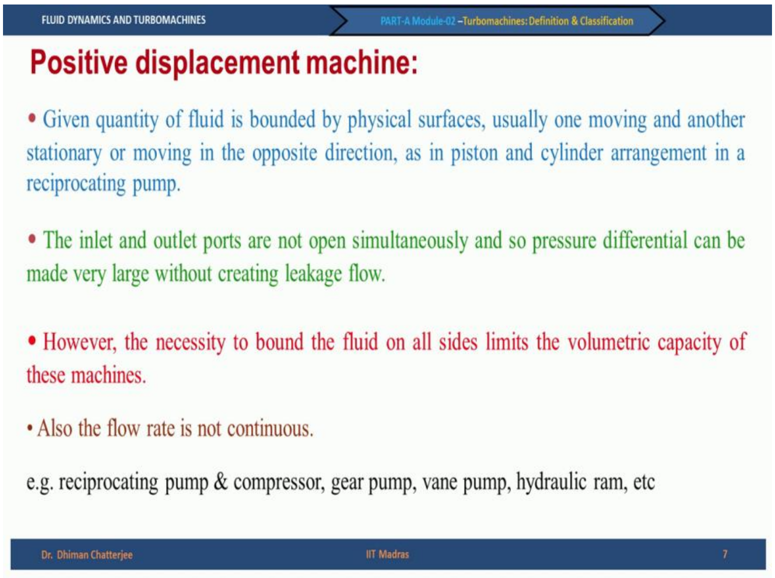

So let us try to summarise what are the features of positive displacement machine. So given quantity of fluid is bounded by physical surfaces usually one moving and other stationary or that may be moving in the opposite direction, like the example of piston cylinder arrangement I just talked about. The inlet and the outlet ports are not open simultaneously and so the pressure differential can be made very large without creating leakage flow. This is a very important point from the performance of positive displacement machines, I will come back to it when I talk about the corresponding point in Turbo machines.

However the necessity to bound the fluid on all sides limits the volumetric capacity of these machines. Let us take the example of the reciprocating pump we just visited. So in this case let us say that the stroke length of the Piston is capital L and the area of the bore of the cylinder is A. Then when the piston moves from one end to the another, the total volume that can be of fluid that can be admitted is A multiplied by L which means that the geometry of the pumps will restrict the amount of fluid that can be handled. So for all practical purposes the reciprocating pumps are used when we need a high pressure rise but when the flow rate is less.

And as I had already mentioned the flow rate is not continuous here, it is discreet as you could see in the case of reciprocating pump and even in the case of gear pumps, there will be ripples, however small the ripples can be. Examples, reciprocating pumps and compressors, gear pump, vane pump, etc. now we know what are the positive displacement machines. Let us look at some aspect of Turbo machines in the same way.

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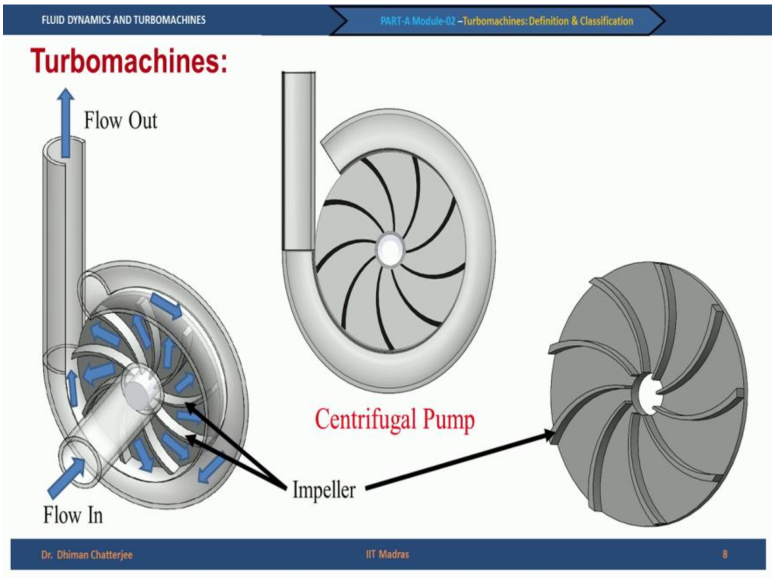

So this is a cutout of a pump which we have shown here, let us first focus on the central figure where we have a cutout of a pump and you can see the blades, I will talk about more about these blades in the later part of the course, the fluid will enter from the centre, here you are showing the pipe is, showing that schematically, then the fluid go through each of these vane passages, the passage between the 2 blades, let us say this blade 1 and the Blade 2, the fluid goes through this vane passage, it is collected in the casing and then the flow goes and comes out through the this delivery pipe. The casing is shown here is only representative, an actual case casings can be of different shapes and that is a part of the discussion we will take up when we talk about the pump.

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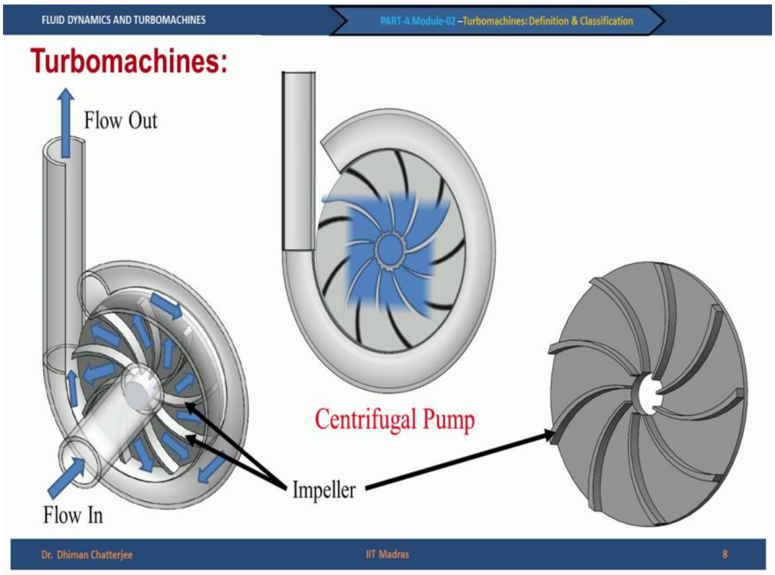

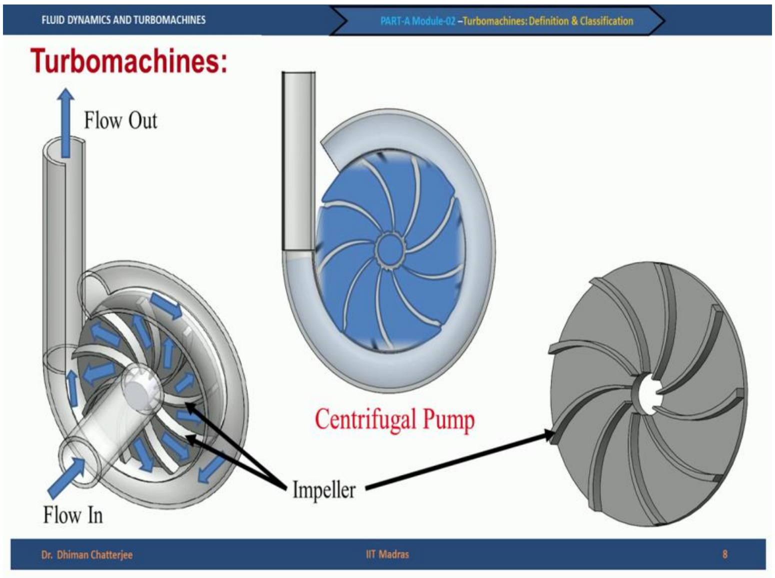
FLUID DYNAMICS AND TURBOMACHINES
PART-A Module-02 –Turbomachines: Definition & Classification
Turbomachines:
Flow Out
Flow In
Centrifugal Pump
Impeller
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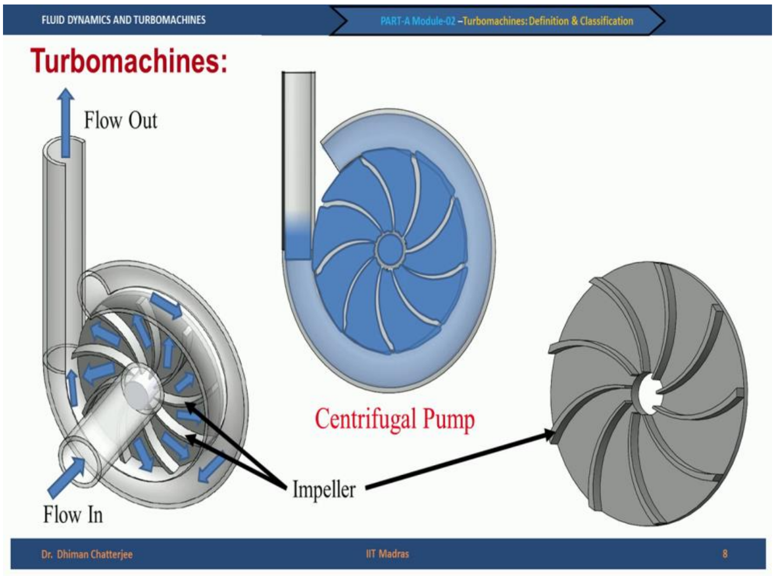
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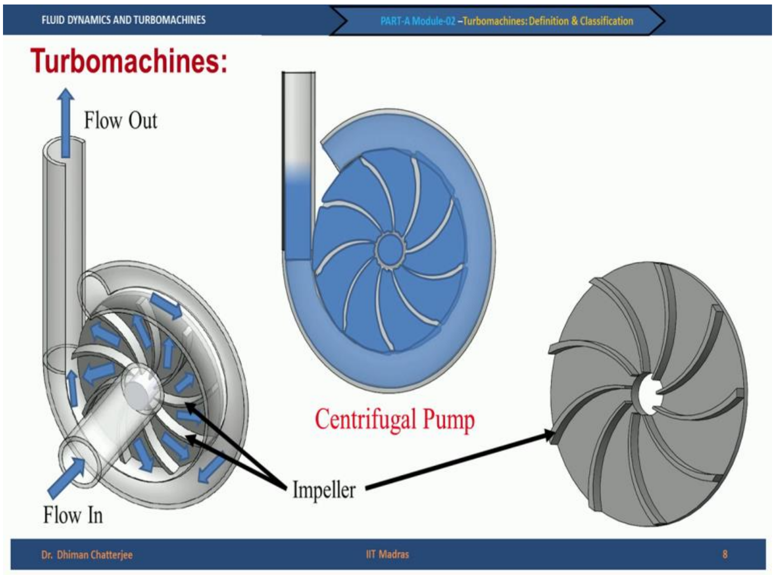
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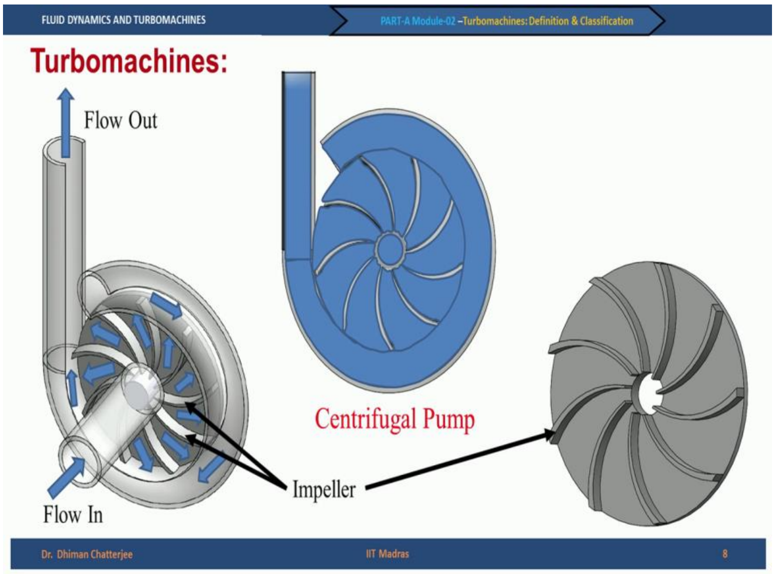

So let us see an animation of how the pump works. Look at the blue colour that will fill this passage, that is an indication of water or any fluid that is being taken in. As the blade rotates, the flow is admitted and the flow leaves through the delivery side. The heart or the main part of any Turbo machine are these blades. You see these blades, the rotating blades, these are called impellers, also shown here in the right-hand side, these are called impellers, they are also called rotors, rotating blades, moving blades and different names. But the main purpose is the transfer of energy from the fluid to the blades or the Blade to the fluid will take place in these rotating blades only.

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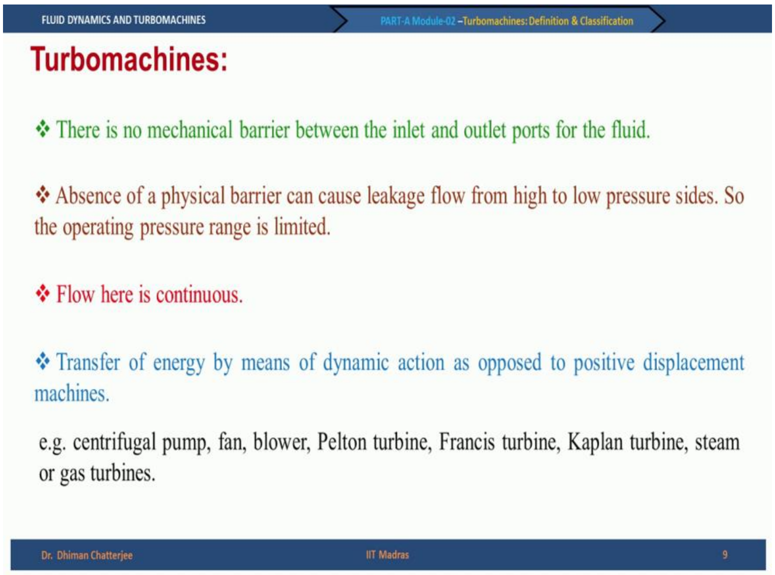

Thursday can say that there are some other is no mechanical barrier between the inlet and outlet ports for the fluid. Recollect what we have said about the use of mechanical barrier in case of positive displacement machines. We said that because of the presence of some kind of physical barrier there is a less chance of leakage flow. So now immediately you can conclude that in case of Turbo machines, in the absence of any mechanical barrier the leakage flow can take place from high pressure side to the low-pressure side and hence the operating pressure range is restricted in comparison with particularly there is positive displacement machines.

So flow here is continuous and there, because the flow takes place because of the dynamic action of the blades. Here there is no gear tooth or the cylinder piston arrangement by which the fluid is taken from the suction side or the supply side to the delivery side or the discharge side. Alright, in this case the blades are rotating but the blades are not themselves responsible directly to take it, take the fluid from the inlet to the outlet as happens in the case of positive displacement machines. Examples centrifugal pump, just now we saw, fan that we use every day in our homes and blowers, different types of turbines like Pelton turbine, Francis turbine, Kaplan turbine, steam or gas turbines. Essentially the names that I have shown you hear we will cover these aspects in greater detail in the coming classes.

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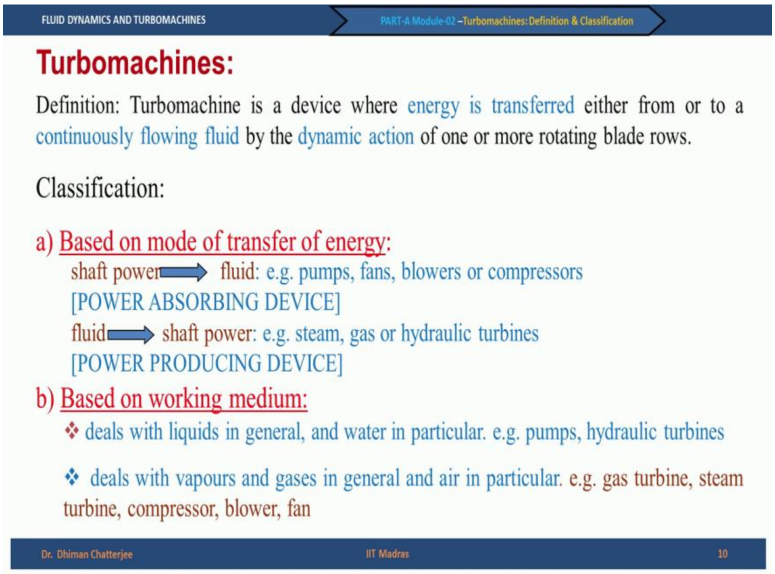

So let us come to the definition of Turbo machines. This definition is very important, so let us look at the definition more carefully. Turbo machine is a device where energy is transferred either from or to a continuously flowing fluid by the dynamic action of one or more rotating blade rows. First the term which has been highlighted is energy is transferred, like I told you the fluid machines, there should be a transfer of energy and that transfer of energy takes place either from the continuously flowing fluid or to the continuously flowing fluid. So that means there are 2 distinct types of Turbo machines. And why continuously flowing fluid is highlighted, to contrast it from the discontinuous flows or ripples flows as we have seen in case of positive displacement machines.

So this brings us to the next item which is the classification of Turbo machines. The first one is obvious, we have already talked about that energy is transferred either from or to, so we can say that based on the mode of transfer of energy we can say that the shaft, if the energy transfer takes place from the shaft to the fluid, that is there is an external agency which makes the shaft to rotate and hence the blades attached to the shaft rotates and that moving blades transfers the mechanical energy into the fluid. As a result of which the fluid energy increases, then we call that as power absorbing device.

The common examples are power pumps, fans, blowers or compressor. If on the other hand the flowing fluid has energy and that energy is extracted by the moving blades and that makes the shaft to rotate and as a result the power is, the fluid power is converted into mechanical energy, then we can say these are power producing devices and the examples are different types of turbines, steam, gas or hydraulic turbines. The next kind of classification that we can say as you have seen the examples is based on the working medium. So based on the working medium we can say that the Turbo machines can handle liquids like that of hydro Turbo machines, particularly water, example pumps, hydraulic turbines.

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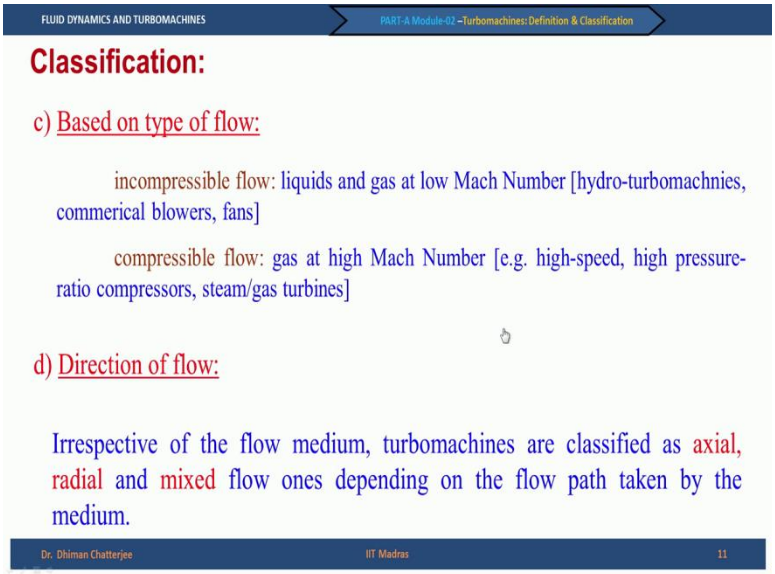

There are other types of Turbo machines which handles vapours and gases and more particularly air, example gas turbine, steam turbine, compressor, blow or fan. We can continue with the classification of Turbo machines further. We can say that based on the type of flow it is we have already studied in fluid dynamics that the flow can be incompressible and compressible. When do we have a flow to be incompressible? When the density changes are insignificant and when the mach number based on the fluid velocity is less than 0.3. So incompressible flow machines are those machines which handles either the liquids or gas at low Mach number.

Thus any hydro Turbo machines, that is pumps and hydraulic turbines as well as commercial blowers and fans are part of this incompressible flow Turbo machines. Whereas if the density changes are significant, so that we cannot neglect the density change effects, as that happens at a higher Mach number, then we can say flow is of compressible flow type and this includes the high-speed, high pressure ratio compressors and steam or gas turbines. At this stage you may ask how does it matter to me if the flow is compressible or incompressible.

The answer is that when we try to design a Turbo machine, we need to keep in mind the underlying flow physics. And hence the need to classify the Turbo machines according to the type of flow. The next and a very important distinction or classification is based on the direction of flow, that is, please remember here when I say the direction of flow, I want to emphasise here that the direction of flow inside the rotating blades. I am not talking about the entire Turbo machine here, I am talking about the inside the rotating blades or so-called impellers, rotors.

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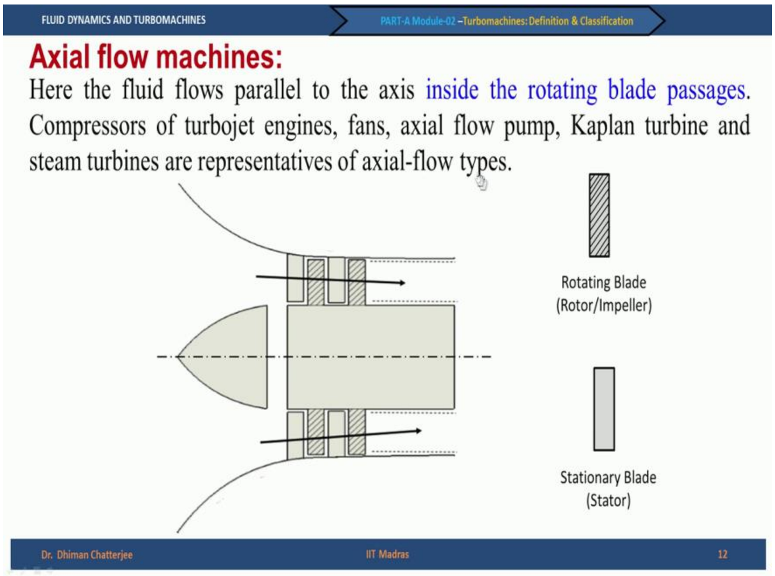

So irrespective of the fluid medium and the type of flows, Turbo machines are classified as axial, radial and mixed ones depending on the flow path taken by the medium. So we will go through each of these one after another. We start with axial flow machines. So here the fluid flows parallel to the axis inside the rotating blade passages. Please note the phrase emphasised here, inside the rotating blade passage, I will get back to this when I talk about the Kaplan turbine. So there are different examples compressor soft turbojet engines, the axial flow fans, axial flow pumps, Kaplan turbines, some of the steam turbines are representatives of axial flow types.

So in this case, this is the hub and you can see that attached with the hub are blades are shown here, so these blades are attached to the moving or rotating shaft and as a result these blades are rotating as shown here and you have another set of blades which are connected to the top casing, which has a distinct gap between the hub and the rotating portion and the stationary portion, these are called the stationary blades or stator. Thus we understand that in types of, some types of Turbo machines, we can have both rotating blades and stationary blades.

And if you keep this arrow direction given, it shows clearly that the arrow is parallel to the axis while it passes from through the blades. But you can also imagine that the fluid could have come from here and at some angles. We still consider this flow Turbo machine to be axial flow Turbo machine because we have made that the classification based on the flow inside the rotating blade passage.

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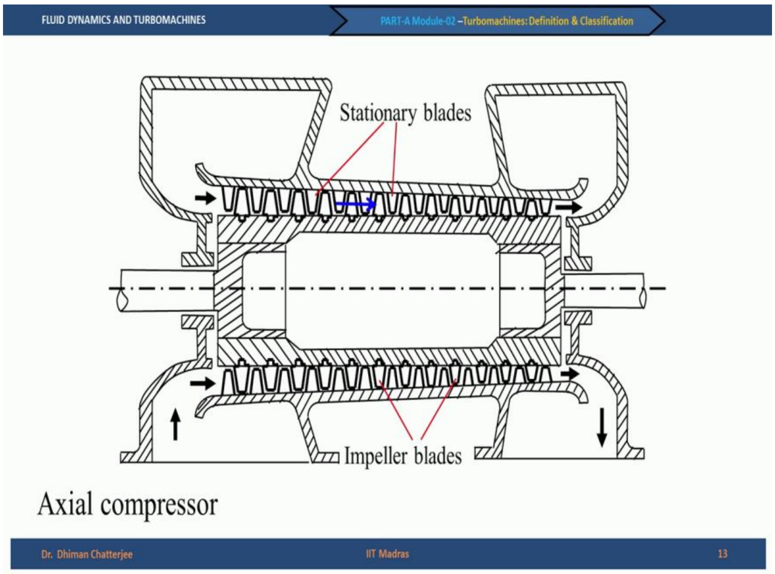

The next example, it is a complicated figure, if we want to take the essential portion or profit, this is an axial compressor, you have the shaft here and this is the hub and you can see a set of blades which are connected with the casing, the outer is the casing, so you can see a set of blades, for example the first one is connected with the casing and these blades which are connected with the casing, they do not move, these are called the stationary blades or stators. On the other hand you have some blades which are connected to the rotating hub which is connected to the shaft, so you see these blades rotate about its axis and these are called the rotating blades, impeller blades or rotor or runner.

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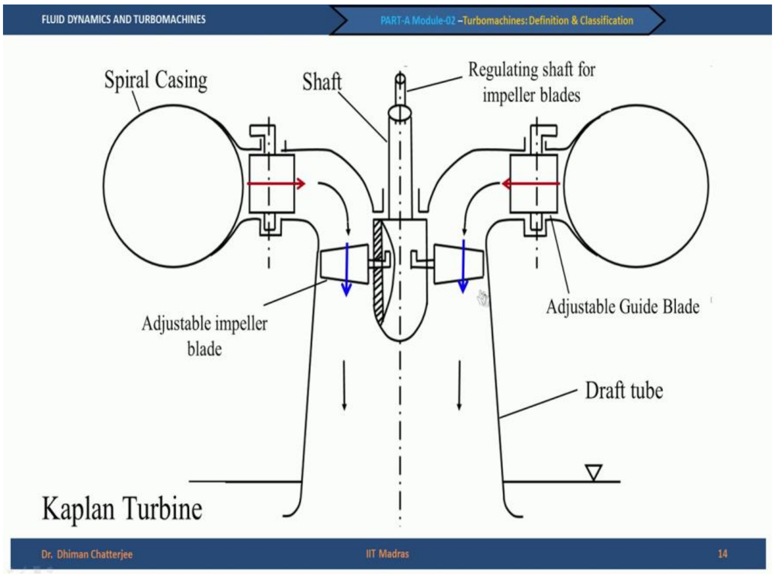

We will use these terms interchangeably because that is what is used by practising engineers in different fields of Turbo machines. So impeller blades, rotors, runners are all the different names that are given to the rotating blades. So now let us look at another example. This is an example of a hydraulic turbine called Kaplan turbine. So you see that the fluid flow comes from here, takes a turn and then flows parallel to the axis. Now if we are not careful, then we may think the fluid direction is radial here, somewhere something, something at some other angle and here it is axial.

But here we call Kaplan turbine an axial flow turbine because of the simple reason that the fluid flow is parallel to the axis when it is in passing through the blade passage which is a rotating blade passage or impeller blade passage. You see here this is a section of a view have shown for the rotating blades which is connected to the hub and the hub is connected to the shaft. So this is the rotating component, other components are stationary, this is called the guide blade, as just like we have talked about the stator. So this is an adjustable guide blade. I will talk about the construction of turbines, the hydraulic turbines later but it is important to note the flow direction inside the runner passage or the rotor passage.

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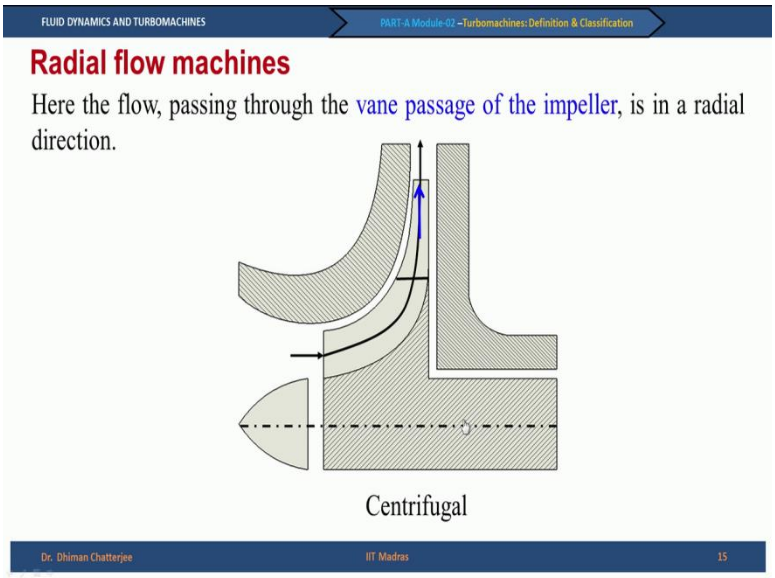

The next type of Turbo machines can be the radial flow Turbo machines. In this case as the name suggests the flow is radial inside the vane passage of the impeller. That means that inside the vane passage of the rotating blades, the fluid flow direction makes an angle of 90 degree with the axis of the Turbo machine. This is also often given a name of centrifugal, so you see the fluid a flow enters from here, take a bend and then this horizontal line is the edge of the blade and hence this portion of the blade as given by the blue arrow, you see the blue arrow talks about the flow direction inside the blade passage and that makes an angle of 90 degree with the axis of the machine shown.

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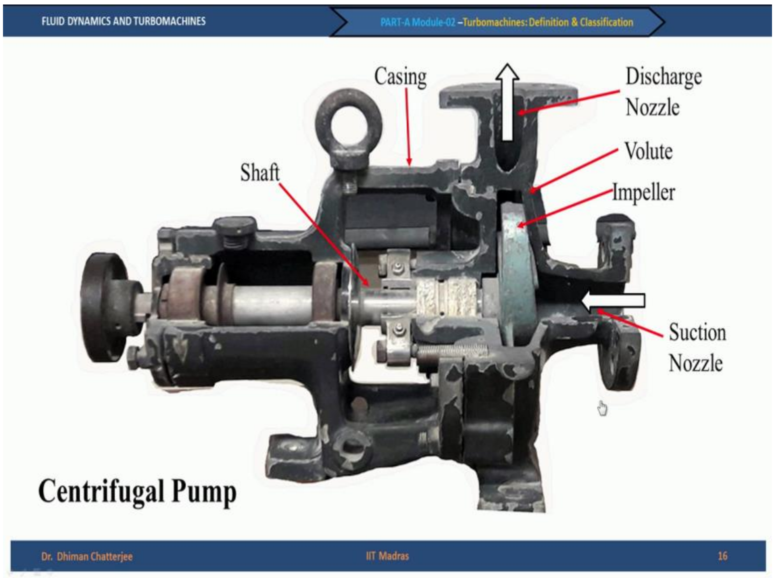

In this case please note that we have only shown the top half impeller, so you should have an expected another vane passage in the bottom which is not shown here. And this is the photograph of a pump whose front portion of the casing is removed so that we can see it better. The flow enters from here, here is, this one is the impeller which is the radial flow impeller in this case of course not clearly visible and then the flow moves out through the discharge. This is the shaft which is connected with the gland packings so that the leakage is prevented, so the water does not come in and in this side here you have the connection with the external drive or the motor.

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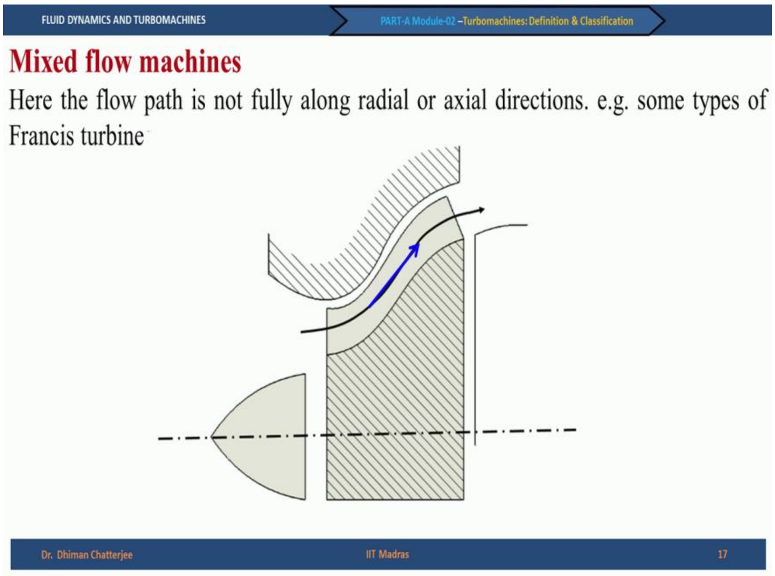

We also have a deflector, you can see this plate during which is given so that deflector actually reflects if any amount of water has come in, so that it does not go to the bearing housing and to the subsequent downstream part into the motor. Last type of machines, which is neither making 0 degree nor making 90 degree with the axis inside the vane passage is known as the mixed flow machine. In this case here the flow path is neither fully radial, nor axial. Example, the different types of Turbo machine like even mixed flow pumps or Francis turbines. So you see here the flow direction as given by this blue arrow makes an angle Theta with the axis and that Theta is neither zero nor 90 degree.

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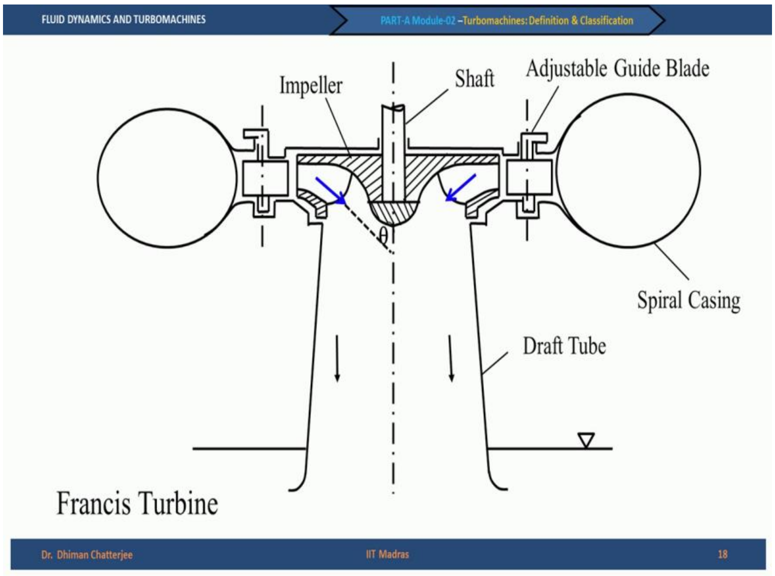

It will become clear when we see a Francis turbine which is it another type of hydraulic turbine. So you see that the fluid enters from the guide blade in this direction radially but when the fluid is passing through the rotating blades or impeller which is connected to the shaft, you see that it makes an angle Theta with the axis and hence this Theta which is neither zero or 90 degree, it is somewhere in between, this is called the mixed flow machine.

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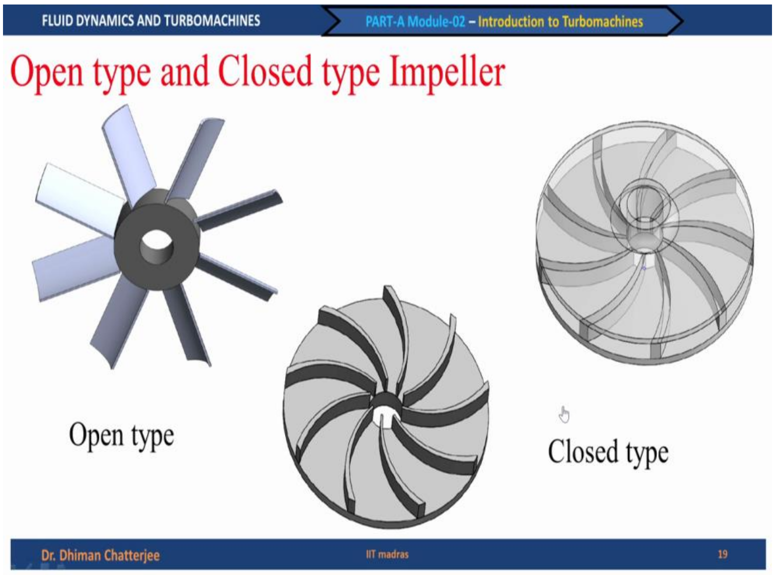

And the impeller which is the heart of this Turbo machine can be of open type or close type. If we see the picture on this one left, it is an open type impeller and the most common example of an open type impeller is the propeller in a ship or a propeller in an aircraft. If you are going in a Turbocraft, the next time you please try to see the propeller, these are open and this is an example of an open type impeller. Then we can have an impeller which is closed, there are 2 types, one in which you have the friend shroud and the rear shroud and of course here it is shown in transparent, so the blades are visible, so these are blades and the gap between the 2 blades is called the blade passage or a vane passage.

This is a closed impeller and in between we can have an impeller where one of the shrouds is absent, this is called a semiclosed impeller. So we have learned the different types of Turbo machines, we have understood the different types of impellers. I will summarise today's discussion with these following points.

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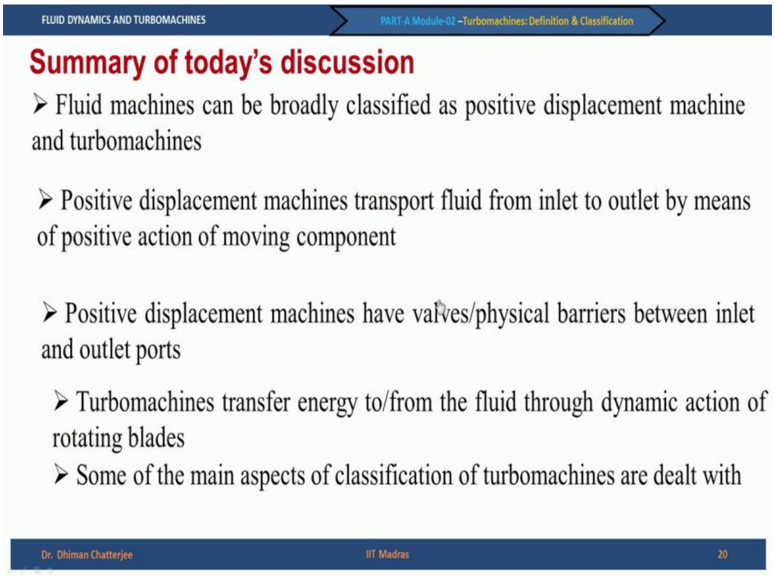

We can say that fluid machines can be broadly classified as positive displacement machines and Turbo machines. Positive displacement machines transport fluid from inlet to the outlet by means of positive action of a moving component. Positive displacement machines are valves or some kind of physical barriers as we saw in case of gear pumps between inlet and outlet ports and Turbo machines transfer energy to and from the fluid through dynamic action of a rotating blades and some of the main aspects of classification of Turbo machines are dealt with.

In the next lecture we will talk about how can we justify for which operating parameters I should go for a radial flow pump or a axial flow pump or a mixed flow pump. To get to know this, there are different ways of doing it and the best way of doing it is by using a nondimensional technique, thank you.