IC Engines and Gas Turbines
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Lecture – 30
Turbomachines

Welcome, to the first lecture on turbomachinery part of gas turbine course. Here, in the first lecture, we will deal with what are the different arrangements of gas turbine and what do we practically mean Turbomachines. So, here as the title suggest we are going to talk about turbomachines. So, question comes in our mind that what is basically this titles meaning is. So, can we have some idea about this title? What does this title turbomachines mean?

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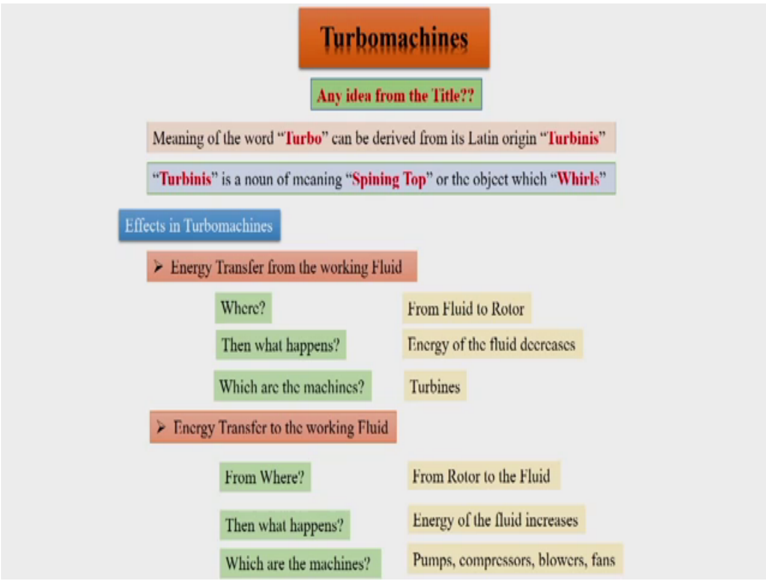

The title turbomachine has it is connection with the latin word terbinis. Terbinis is a latin word which is a noun and its meaning is spinning top or the object which whirls; that means, which rotates. So, turbomachines would deal with the machines which are rotating machines or the machines in which the parts of it are rotating; so this is what the turbo machine definition is.

And, now we will have something to extra do with what then turbomachines will have. What are the effects which a turbomachine can deal with? So, there are two kinds of effect in first kind of effect there will be energy transfer from the fluid. Obviously, this has these are turbomachines or fluid machineries. So, there is work transfer from the working fluid. So, there is some working fluid in case of water turbines we have seen that their water is the working medium and in case of gas turbines we have working medium as air or any other gas.

So, in the first effect of the turbomachines there will be energy transfer from the working fluid. So, where this energy transfer will take place from the working fluid? And, the answer is it will transfer from the fluid to the rotor; that means, the working fluid will have certain energy and it will transfer it is energy to the rotor and in this action or this transfer would lead to the motion of the rotor. So, then what happens this question is specifically for the working fluid. Obviously, the working fluid would lose it is energy in the phase of energy transfer.

Which are the machines which deal with such energy transfer from the working fluid to the rotor? Then these machines are basically turbines. Obviously, the second effect in the turbomachines is energy transfer to the working fluid. Here what we are trying to understand is there will be reverse energy transfer. So, actually working fluid will receive the energy. Then from where the working fluid will receive the energy? Working fluid will receive the energy from the rotor.

And, then what happens obviously, since there is certain energy to start with to the working fluid and then it is going to receive the energy from the rotor it will increase its energy. So, working fluid will have increased energy due to the energy transfer from the rotor to the working fluid. Then, what are the classes of machines which will have energy transfer from the working fluid to the rotor? And, examples are pumps compressors blowers and fans.

So, when we deal with turbomachines we have two kinds of energy transfer energy can transfer either from the working fluid to the rotor or from rotor to the working fluid.

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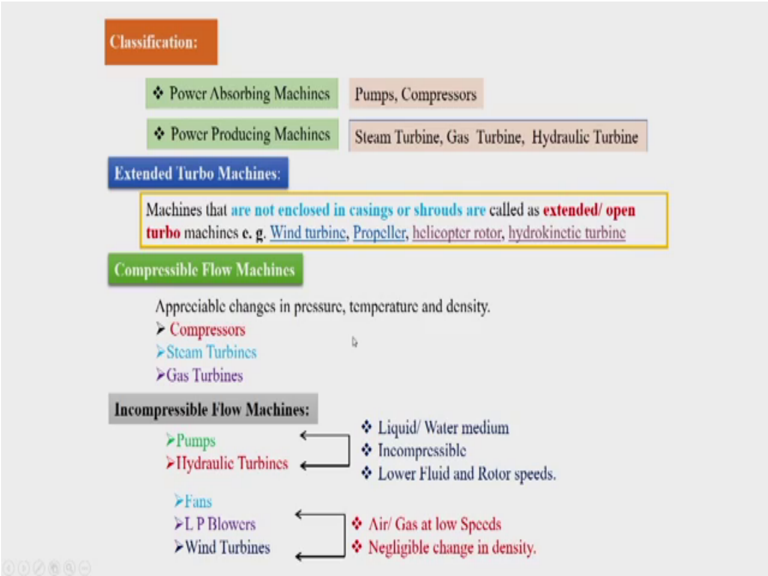

Then, these machines can be classified. So, one class of machines are power absorbing machines and other class of machines are power producing machines. In case of power absorption machines we have pumps and compressors. So, in case of pumps and compressor power is getting absorbed.

So, actually in case of pumps and compressor working fluid will receive the energy, so, these are power absorbing machines. In case of power producing machines examples are steam turbine, gas turbine, hydraulic turbines. So, in these machines basically fluid is going to release the energy leave the energy or give the energy to the rotor. So, this will lead to decrease in energy of the fluid; so these are power producing machines.

Then, there are certain other types of turbomachines and in those other types of turbomachines we have extended turbomachines. These machines whatever we have talked about like pumps, compressors or any kind of turbine these machines are a kind of machines where we have a casing. So, rotor is bound by a casing, but in case of extended turbomachines there will not be any casing or any shroud there will not be any casing or shroud which will cover the rotor. So, these machines are called as extended turbomachines; example is wind turbine.

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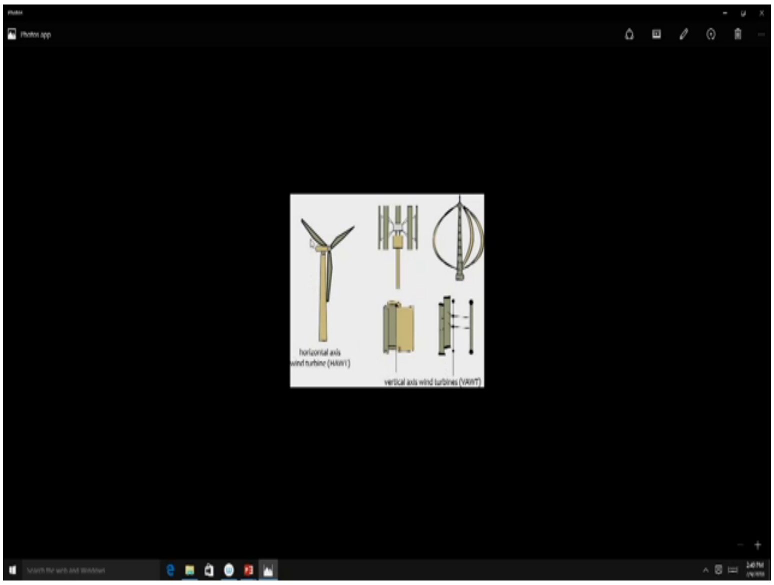

So, in case of wind turbine we can see that the blades of the wind turbine are completely open; there is no cover for this blades.

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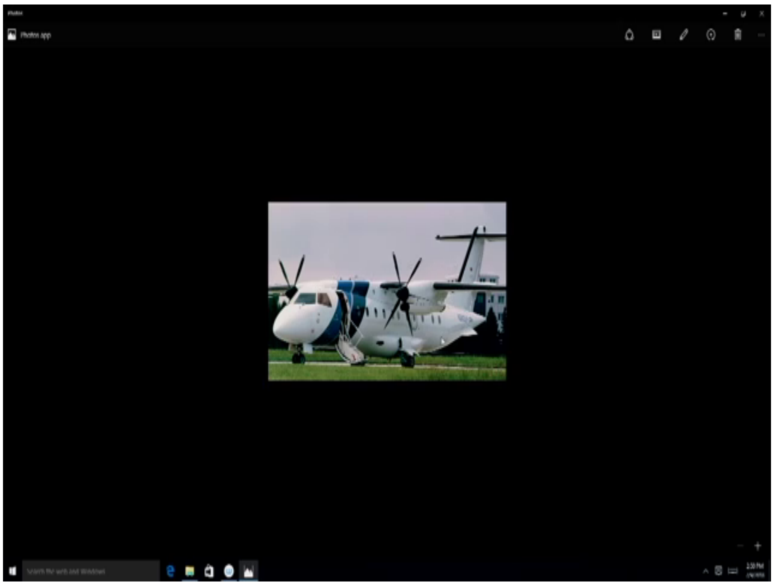

Similarly, there is another example of propeller. Propeller of an aircraft is also an extended turbomachine.

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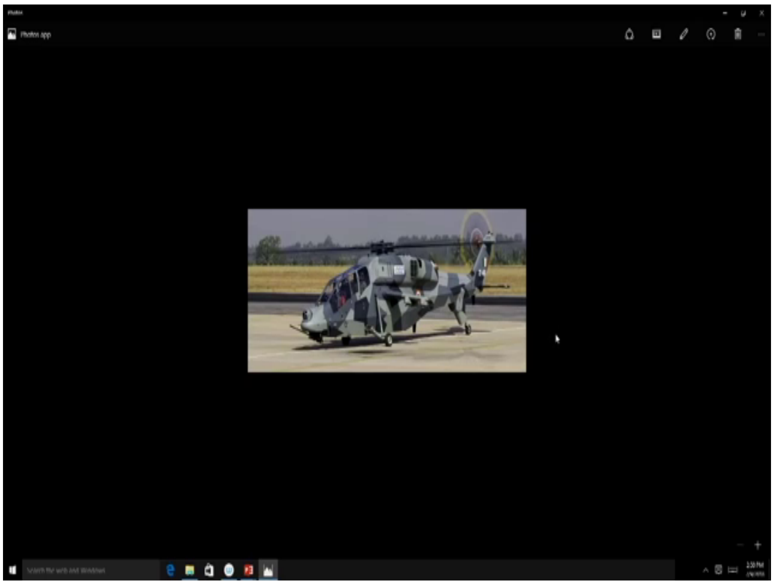

Then, there is helicopter blades and helicopter blades are also extended turbomachines.

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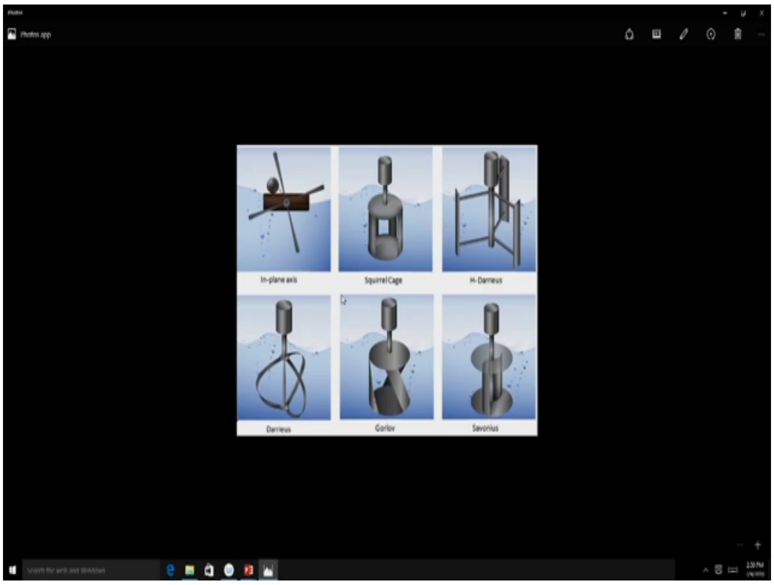

Further, there is one more examples which is called as hydrokinetic turbine. In case of hydrokinetic turbine e also see that these are the turbine which are immersed in water. So, they are open for large amount of water. So, since it is the case these are also called as extended turbomachine further.

Then, turbomachines will actually be defined based upon the working medium they are getting used. So, one working medium is called as compressible flow machines. If turbomachines deal with a working medium which would lead to large number of or large amount of pressure change, temperature change and density change, then such turbomachines are called as compressible flow machines. Examples compressors steam turbines and gas turbines.

So, compressible flow machines would lead to large amount of pressure, temperature and density change as we would be knowing in case of gas turbine, compressors and steam turbine. In fluid mechanics practically these machines deal with very low speed of the working medium. Compressible flow machines are the machines which deal with the large change of pressure temperature and density variations. So, examples are compressors, steam turbines and gas turbines.

So, these machines have their working medium where upon their work there is large change in pressure, temperature and density. In fluid mechanics these machines actually deal with large amount of velocities and these large amount of velocities will practically lead to large changes in pressure and temperature. So, compressible flow machines are the machines where pressure, temperature and density changes are expected large in quantity.

Then, we have incompressible flow machines. So, in case of incompressible flow machines it would be exactly rivers such that pressure, temperature and density changes are expected to be very low, minimal, or low. So, examples are pumps or hydraulic turbines they deal with liquid water; so water being liquid it is incompressible. So, since it is incompressible there is very long little amount of change or rather practically no amount of change in density of water. So, these are incompressible flow machines and they deal with lower velocity as it was expected.

Then, we have some turbomachines which deal with non incompressible materials or we are having materials which are compressible basically like air, but these velocities which machines would be dealing like fans, L P blowers which is low pressure blower or wind turbine they deal with air, but they deal with air at very low speed. Since air is getting dealt at low speed the associated air pressure, temperature and density changes are less. So, since these density changes and pressure changes are less the machines like fans, L P blowers and wind turbines are incompressible flow machines.

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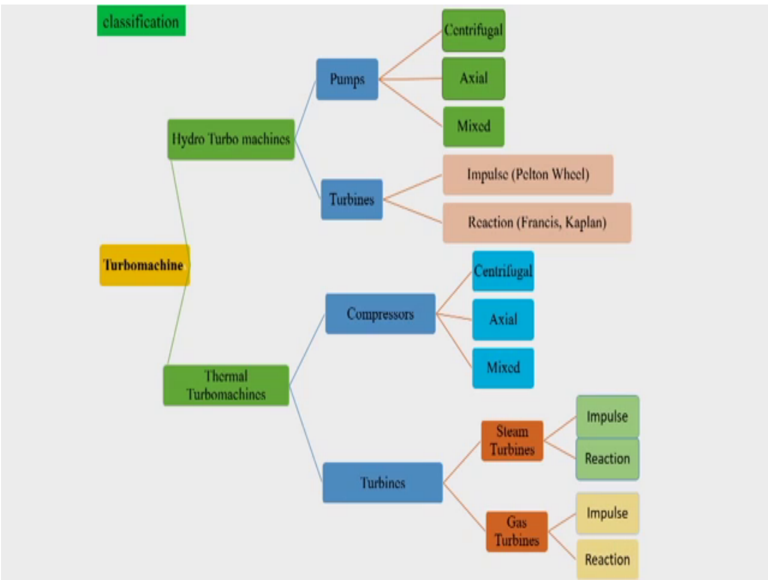

Then we have classification of all the turbomachines. So, turbomachines can be broadly classified into two categories; one is hydro turbomachinery and other is thermal turbomacineries. So, in hydro turbomachineries as we know we have pumps and turbines. In thermal turbomachineries we have compressors. Basically pumps do a job which is getting then in thermo machineries by compressors and the second is again turbines.

Then, in case of pumps we have centrifugal pump axial pump and mixed flow pump. In case of hydro turbines we have impulse turbines like Pelton wheel or we have reaction turbine like Francis and Kaplan. Then we have compressors; we have compressors like centrifugal, axial and mixed flow compressors. In turbines we have steam turbines and gas turbines further in case of steam turbine we have impulse turbine and reaction turbines and in case of gas turbines also we have impulse turbines and reaction turbines.

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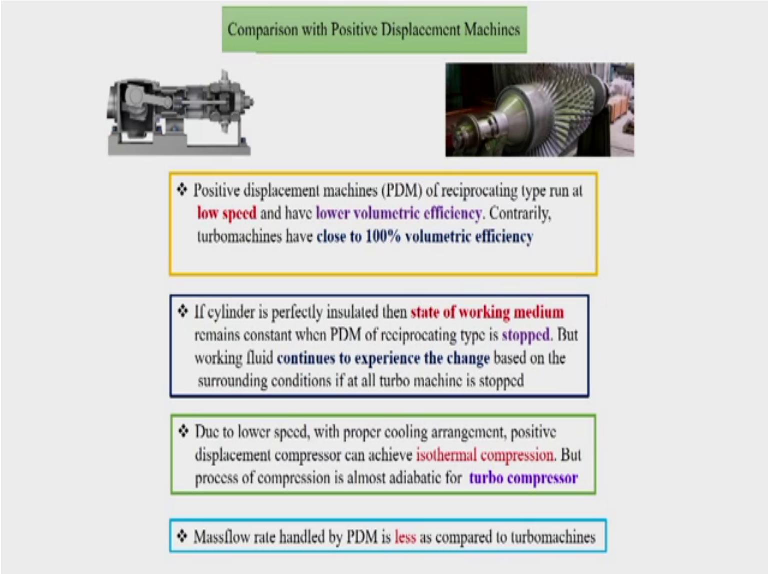

Then, turbomachineries whenever they are compared they would generally be compared with positive displacement machine. So, as you can see and one side we have piston cylinder arrangement and on other side we have an arrangement where we have a shaft and on which a rotating object is kept that a rotating object would; obviously, rotate due to the motion of shaft. Here in case of piston and cylinder arrangement piston will move inside the cylinder due to the it is connection with a shaft, but motion of the piston is to and fro in the cylinder.

This machine which is a reciprocating machine is having walls and due to presence of these walls this machine would have changes in the boundaries and that would lead to the change in properties of the working medium, in such case these machines are called as positive displacement machines. So, in case of positive displacement machine also we can get similar outcome which we otherwise can get in case of turbomachinery, but there are some advantages and some merits of turbomachines over the positive displacement machines.

Positive Displacement Machines or what we call it as PDM are capable to run at the speeds which are much lower than the possible speeds which can be achievable by the turbomachineries. There is one more problem of positive displacement machines and that is the volumetric efficiency. They do not run with very high volumetric efficiencies, but in case of turbomachines volumetric efficiency is close to 100. In case of positive displacement machines if we imagine that cylinder is having certain working medium and then piston is moving, but if piston stops due to some reason in a particular position then the working medium also would remain in it is thermal state or thermodynamic state for the period in which the piston is not running. But, it is not the case in case of turbomachines. In case of turbomachines if at all rotor is stop moving the working medium wood experience the change based upon the surrounding condition.

Then, due to lower speed or possible lower speed in case of reciprocating machines or positive displacement machines what would be happening is there is a large chance that with proper cooling arrangement we can attain isothermal process as in case of compression. So, if we have positive displacement reciprocating compressor then we can attain isothermal compression, but in case of turbomachines such thing is not possible since the thermodynamics process is an adiabatic process in case of turbomachines. Mass flow handled by the positive displacement machine is much less than the mass flow handled by the turbomachines.

So, this difference was necessary to know at start of the course since there are very great number of advantages of turbomachines where we practically cannot use the positive displacement machine. So, positive displacement machines can be of compressor type or can be of expander type. So, in case of compressor type we have turbo compressors or in case of expander type we have turbines.

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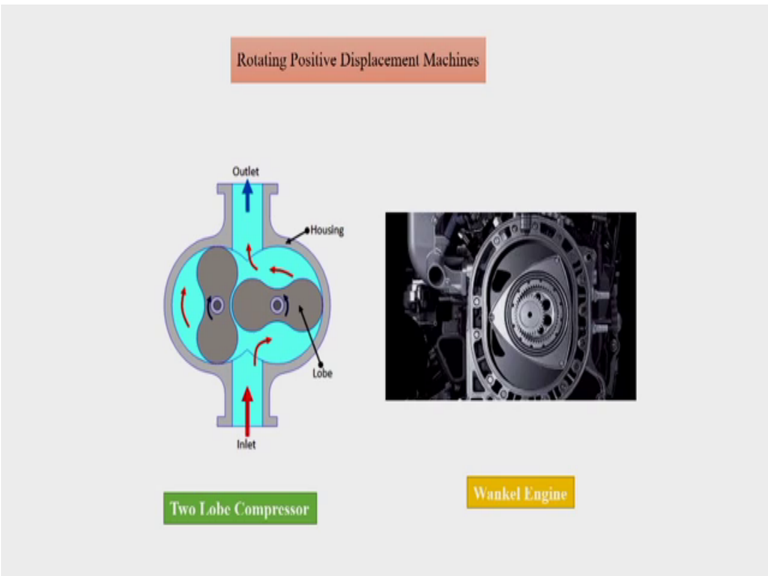

Then, we have, but some machines which are positive displacement, but still rotating machines; an example is two lobe compressor and other example for the engine is Wankel engine. As we had seen the reciprocating compressor or reciprocating kind of positive displacement machines will have motion of the piston inside the cylinder. But, in case of two lobe compressor or in case of Wankel engine the rotor will be having rotary motion and that would lead to compression or work output as in case of Wankel engine.

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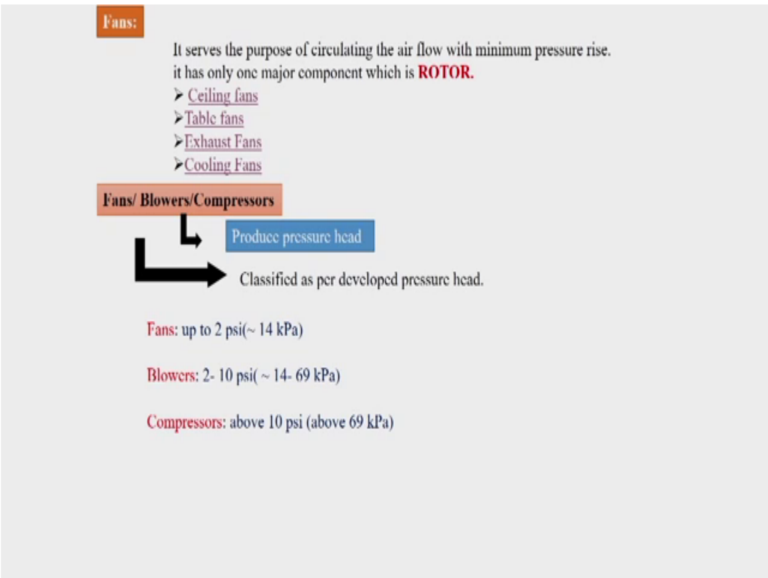

Turbomachine as what we have seen a kind of fan we have seen that the fans are the turbomachine. So, here we are starting first for fan, it is a simple turbomachine and it has only one component and that is rotor. Fans basically lead to a minimal or a small amount of pressure rise.

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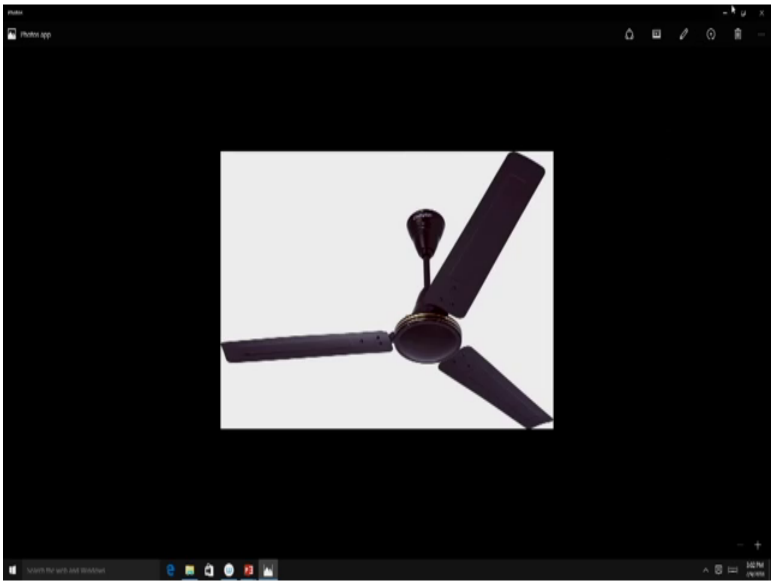

So, the objects which are coming under the category of fan are ceiling fan as what we see in our offices or in our home.

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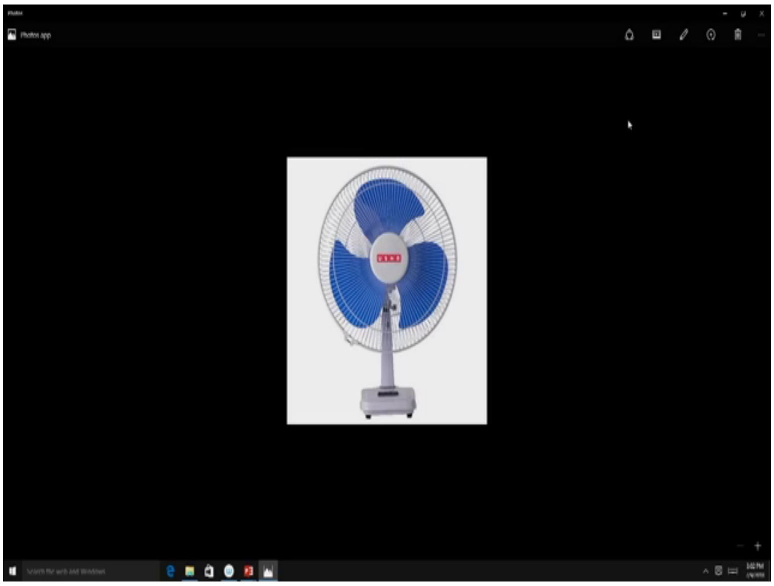

Then, we have table fans as what we can see in our office or in our home.

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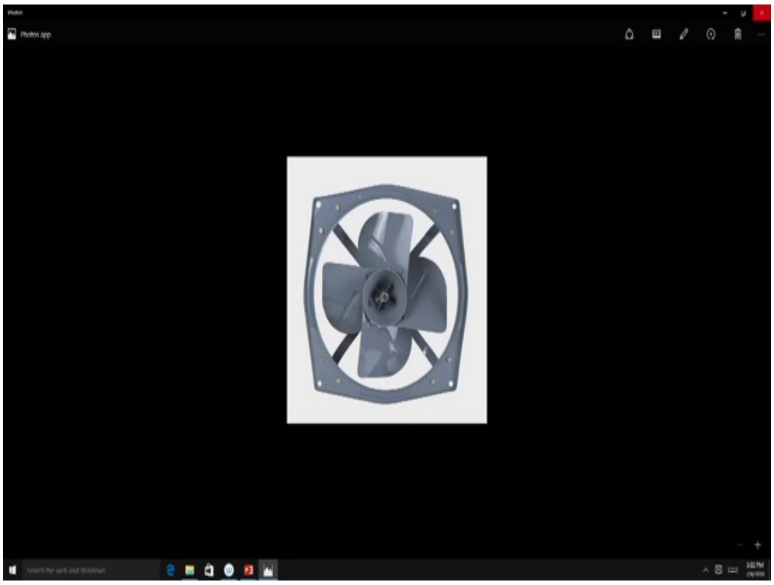

And, then we have exhaust fan in the kitchens most of the times.

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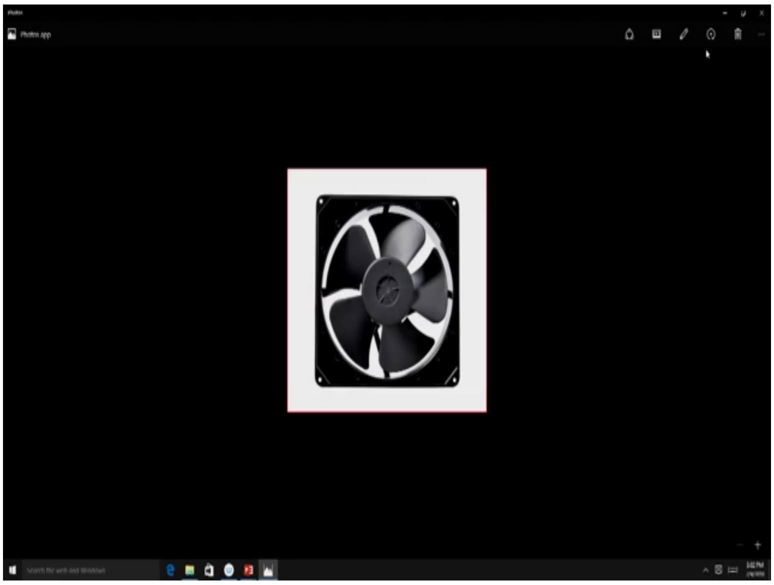

And, then we have cooling fans what we can see for the computers.

So, these fans would actually be implemented mainly for circulation of the working medium and in such case they would lead to small or very minimal amount of pressure rise.

So, there are such three objects practically which are the rotary machines and which would lead to pressure rise first is fan, then we have blowers and then we have compressors. So, fans are the machines which lead to minimal pressure rise; further more pressure rise would be attained by the blowers and then higher pressure rise among these three or higher pressure rise among these three would be attained by the compressors; so they increase the pressure head.

So, this classification of a rotary machine being fan, blower or compressor is based upon the amount of pressure head which is generated. So, in case of fan it generates a pressure head which is around 14 kilo Pascal; in case of blowers the range of pressure rise which it would attain is 14 to 69 kilo Pascal and in case of compressor it is above 69 kilo Pascal; so compressors give highest pressure rise. Basically, compresses are used to increase the pressure fans are used only to move the working medium and blowers are generally used to take care for the head loss in the piping system.

So, these are the classifications of the machines which come under the process which lead to compression for pressure rise. There is one more element which would again lead to pressure rise and that is diffuser, but diffuser leads to pressure rise not due to rotary motion, but due to its internal geometric arrangement. So, there is no rotary part in the diffuser. So, this does not come under the category of turbomachines.

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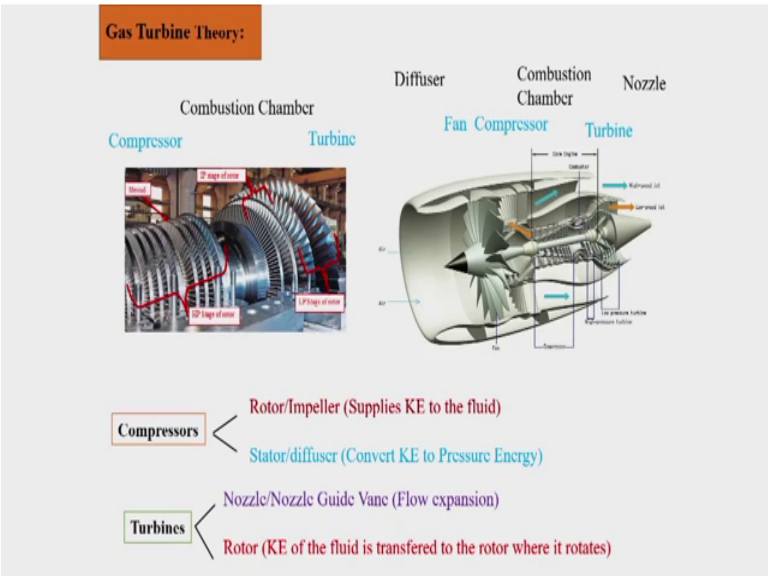

Then, we start dealing with gas turbine theory here we presently deal in first few lectures about the components and their arrangements.

So, in case of gas turbine; so, this is a typical picture of gas turbine which is used for electricity generation. So, display of turbine has a compressor, and then it will have a combustion chamber, and then it will have a turbine. We have purposely marked compressor and turbine at one level and combustion chamber at other level so as to know that among the three components compressor and turbine are their rotary machines and combustion chamber is a stationary object.

Then, there can be gas turbine which would not be used for electricity generation, but would be used for aircraft propulsion. In this case we have diffuser, we have fan and compressor then we have combustion chamber we have turbine and then we have nozzle. So, among them again diffuser, combustion chamber and nozzle are the stationary parts of the gas turbine used for propulsion system and fan, compressor and turbine are the turbomachines or rotating parts of the gas turbine.

So, compressor it would have two parts internally. So, as we have seen that gas turbine if it is used for electricity generation or for propulsion compressor is its integral part. So, if there is a compressor then it would have two parts, first part is called as rotor or impeller which supplies kinetic energy to the fluid. We have seen in earlier slide that it is a power absorbing machine where energy transfer takes place from the rotor to the working medium. So, rotor or impeller supplies the energy to the field; and other object is called as stator or diffuser which converts the kinetic energy to increase the pressure head; so these are the two parts of the compressor.

Similarly, turbine wheel again have two parts and one part is called as nozzle or nozzle guide vane and that generally creates the expansion of the working medium and it generates kinetic energy of the working medium required. And that required or generated kinetic energy is used in the second component of the turbine and that is rotor. So, as we have seen in earlier slide rotor is a power or turbine is a power producing machine. So, in case of power producing machine energy comes from the fluid to the rotor.

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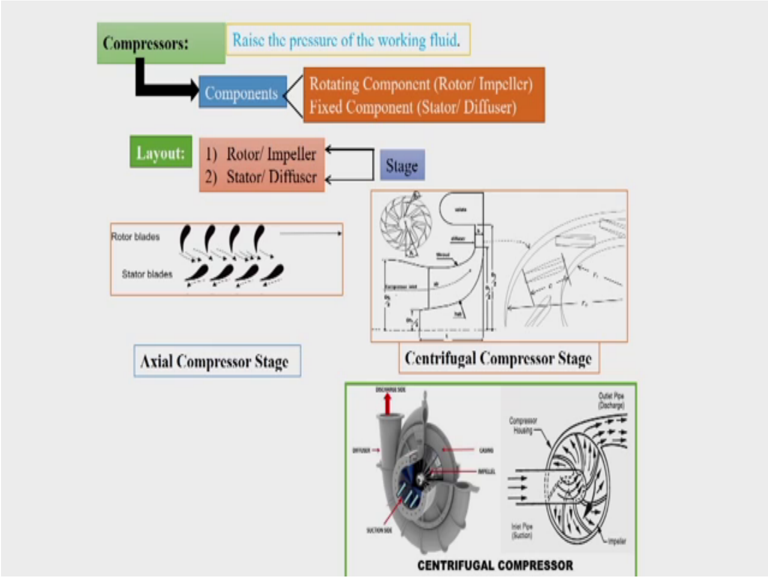

So, little detail of the compressors; so compressor are used to rise the pressure head. So, their components are rotors and the fixed components are stators. So, then, how are the stators and rotors arranged? So, layout of a compressor we will see that there is first element which fluid medium will see in its encounter with the compressor is a rotor or impeller and in case once it passes over the rotor or impeller it passes over the stator or diffuser and a combination of rotor and stator comprise a stage of compressor.

So, this is a typical axial compressor where we have rotor blades and we have stator blades and fluid comes from top to bottom and then this rotor would rotate in this direction as indicated by this arrow. So, this is typical arrangement for a stage in case of axial compressor. But, in case of centrifugal compressor arrangement is similar, but they will rotate in the rotary direction in this blades. So, these blades will be rotating and fluid will first passed through this blades and then it will go to the diffuser. So, this is the centrifugal compressor stage; so this is a typical pictorial view of the centrifugal compressor.

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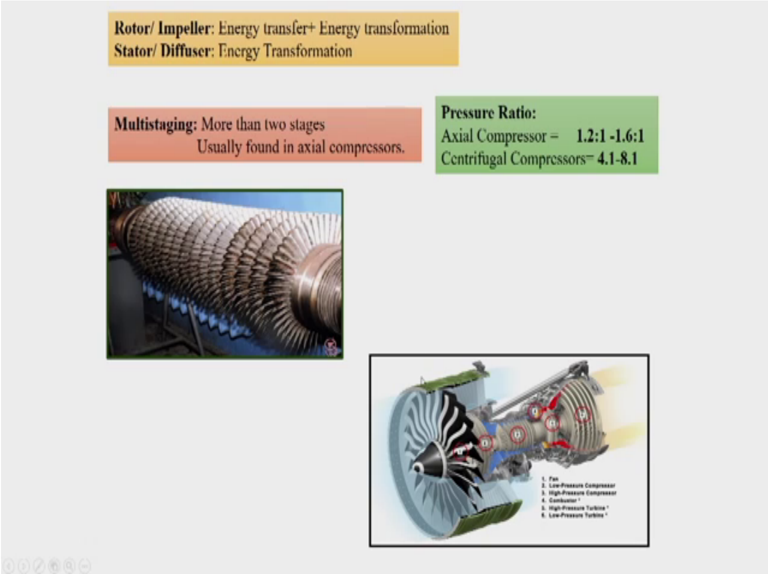

So, as we have seen there is a rotor in centrifugal compressor or in case of axial compressor it would have done two jobs. First job is to transfer energy, as we know that their rotors energy will get transfer to the fluid. But, apart from that internal arrangement of the rotor blades would also lead to energy transformation. Here we mean bi energy transformation that one form of the energy will get converted into other form of energy.

So, rotor job is to transfer energy from itself to the working medium and arrangement between the rotor blades would lead to energy transformation we are going to see these details when we come for the compressor, but in case of stator we do not have energy any energy transfer, but we just have energy transformation. The energy which is gained from the rotor would be completely transferred for generating the pressure head in case of stator; partially it would have done in case of rotor which is called as energy transformation in rotor.

Then, we have multistage compression and multistage compression, there we will have multiple compressor stages which would be clubbed together to get higher pressure rise. But, this is more typical in case of axial compressors in case of axial compressor stage pressure rise is very low it is around 1.2 to 1.6 and in case of centrifugal compressor it is little larger with around 4 to 8. So, these are the typical pressure rise values for a stage in case of axial and centrifugal compressors. This is a picture of centrifugal axial compressor and this is axial compressor with fan arrangement.

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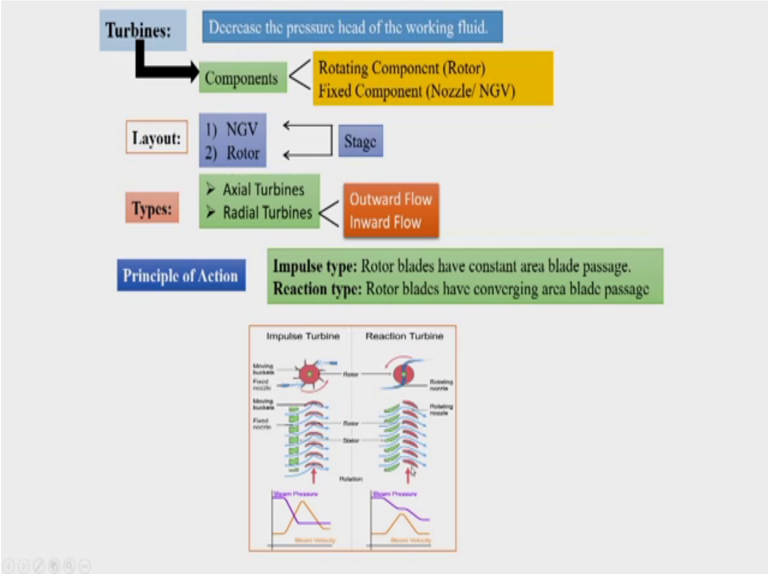

So, in case of turbines now we are seeing that what is the job of turbine? Turbines job as it is stated in earlier slide that it is a work producing machine. So, it is bound to decrease the pressure head. So, pressure head of the working medium would decrease since working medium is going to lose its energy from itself to the rotor of the turbine.

So, components of turbine; again we know that there are two components of turbine. One is rotating component which is rotor and fixed component which is nozzle or nozzle guide vane. But how is the layout of these two components? The in case of turbine we will first have nozzle guide vane and then rotor, it is completely reversed as in case of compressor. In case of compressor rotor was first and stator was later, but in case of turbine in a stage we have nozzle guide vane first and then the rotor.

So, types: we have axial turbines and we have radial turbines. In case of radial turbines there are two categories radial flow turbine will have flow going outward or flow coming inward. So, in case of radial turbine we have outward radial flow turbine or inward radial flow turbine, but in case of centrifugal flow compressor we have outward centrifugal compressor.

So, principle action in case of turbines there are two types of principle actions which are going to take place while transferring the energy from the fluid to the rotor. In one case the energy transfer will take place such that the passage between the rotor blades is constant. The fluid will pass between the two rotor blades in the passage between the two rotor blades and that passage is a constant area duct. So, then in such case such turbines are called as impulse type of turbines where we have transfer of energy due to impulse, but in case of reaction we have the passage between the turbine blades is converging. So, due to convergence we have their some pressure head change in the rotor blade also which is not happening place in case of impulse turbines.

So, this is a typical arrangement of impulse turbine and this is typical arrangement in case of reaction turbine. As we see the rotor blade passage is a constant duct in case of impulse turbine, so, the fluid medium will directly impact on the blades and rotate it. But, in case of reaction turbine the passage is arranged such that there will be pressure change on the rotor blades or during the rotor blade movement of the fluid and then there will be plus some velocity decrement. So, this leads to the power generation from the turbine.

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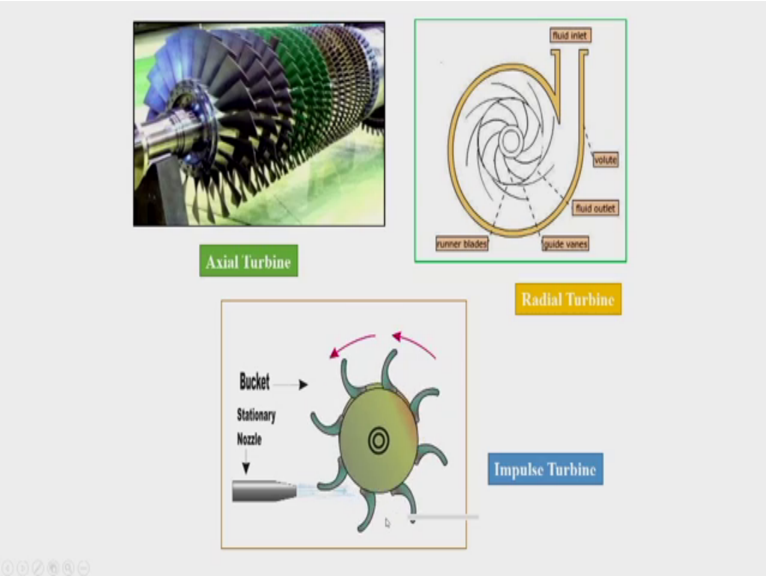

So, this is axial flow turbine pictorial view and this is radial flow turbine and then as we know in case of water this is an impulse turbine. This is a principal demonstration for an impulse turbine.

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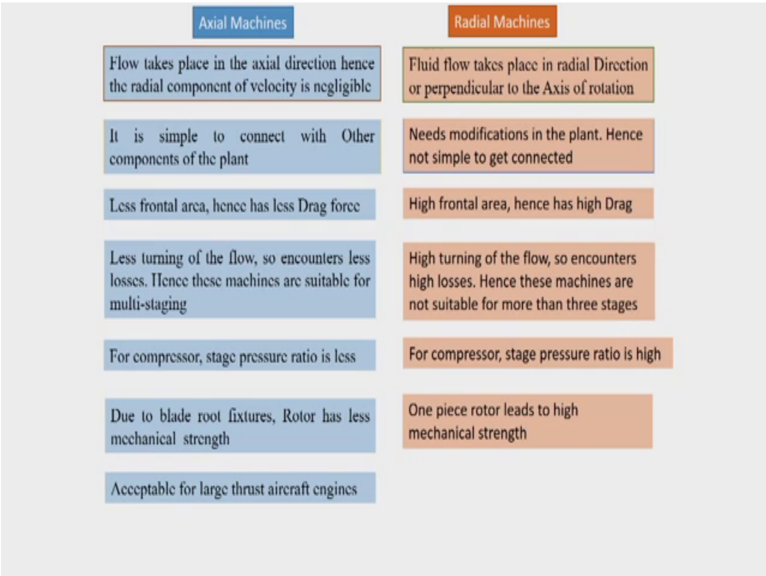

So, what is the difference or advantage between axial flow machines and the radial flow machines. So, as we have seen this difference is for let it be compressor or let it be turbine.

So, what are the differences between axial and radial flow machines? So, in case of axial flow machines as name indicates, the flow takes place along the axis if rotor is rotating in this direction then working medium goes along the axis of the rotor. Since its major movement is along the axis radial component of velocity is negligible or closed to 0, but in case of radial flow machines the movement of the fluid is along the radius. So, radial component is dominant and axial component in negligible.

There is a difference one more such that it is possible to connect axial flow machines quickly or with simple modifications with other components and this is a great advantage for making a plant, but in case of radial flow machines we have to make special arrangements to connect them with the other parts of the power plant. Secondly, thirdly rather axial flow machines need lesser frontal area for interacting with the fluid medium and hence they have lesser drag. But, radial flow machines have higher frontal area and hence they have higher amount of drag while working with the fluid medium.

Then, in case of axial flow machines flow is going to take place along the axis and then there is minor deviation in the flow path and this leads to lesser losses in case of axial flow machines, so, they are much suitable for multi staging. But, in case of radial flow machines there is a large dealing with the turning of the flow and this will introduces large amount of loss with the fluid in case of radial flow machine. So, radial flow machines are not used generally if there are stages more than three number.

In case of compressor, if we are using an axial compressor we can go with higher pressure or the pressure ratio which is particularly less in one stage, but very high pressure ratio in general since multi staging is possible. But, contrarily in case of radial flow machines and those compressors one stage has high pressure ratio, but we cannot have multiple stages connected for multi staging.

Then, we have due to having the fixtures are to be at the root of the rotor we have problem of mechanical strength of axial machines. So, the blades are connected to the rotor for which grooves are made on the rotor. So, this reduces the strength of the axial flow machine. But, we have one piece rotor in case of radial flow machines and in that makes it a good mechanical strength object. So, axial flow machines as we have seen that they are having lesser frontal area and hence they are having lesser drag they are very much suitable for aircraft operation applications, but radial flow machines are not much suitable for aircraft applications.

So, those were the major differences between axial and radial flow machines. So, accordingly whatever be our application we have to choose a proper axial or radial flow machine and we have seen one more thing that there are objects or turbines or compressors which are impulse turbines.

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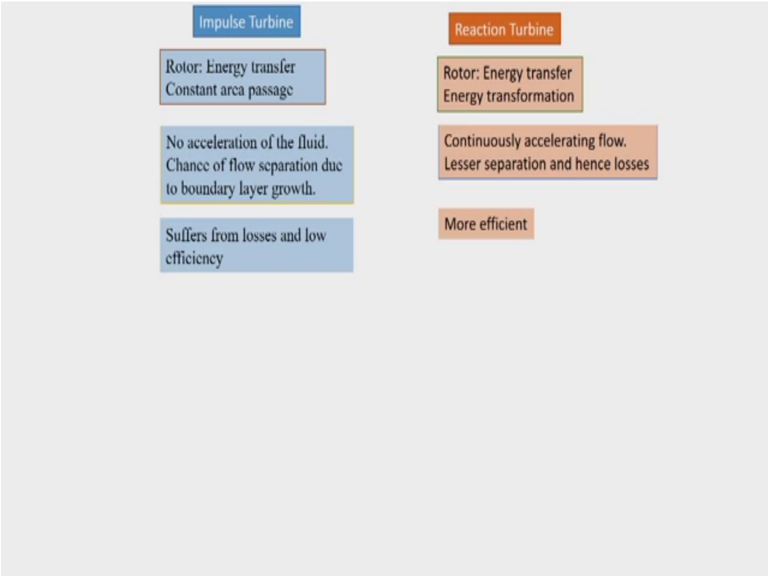

And, we have in reaction turbines there is a certain difference between impulse and reaction turbines. So, in case of impulse turbines we have seen that there is energy transfer in the rotor and they are having constant area passage. But, in case of reaction turbine there is energy transfer and energy transformation in the rotor since the rotor blades are having a passage which is a converging duct.

In case of impulse turbines, there is no acceleration of the fluid possible while flowing through the passage of the blade. Since there is no acceleration possible and then there is growth of boundary layer over the blade passage the chance of separation is high. So, there is a large chance of boundary layer separation in case of impulse turbine, but contrarily the flow in reaction turbine is continuous. So, there is and it is accelerating so, there is less chance of boundary layer separation. So, impulse turbine suffer problems of losses due to boundary layer separation. So, they would have lesser efficiency in general, but reaction turbines are more efficient since they do not encounter much losses over the rotor, since over the rotor we have acceleration of the working medium.

So, this is the interaction in the first class where we have dealt with the different types of turbomachines, their classifications, the components of the gas turbine power plant which is compressor and turbine, and then we have dealt what are the internal components of the compressor, what is the job of each component of the compressor and what are the types of compressor. And, then we have seen what are the types of turbines, what are the internal components of a turbine and what are their functions.

So, we will see further in the next class.