Aircraft Propulsion

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Lecture 03
Turbomachines

Welcome to the class now we are going to see the turbo machines. So, today's class has a topic of discussion as turbo machines, we have seen that there is a cycle thermodynamic cycle upon which an engine can be best. So, the engine of our interest for the course is basically gas turbine engine and for that there are different parts but this engine at gross is called as turbo engine.

So, there is a word which is inherently used as turbo and this word also appears here in the topic which is turbo machines.

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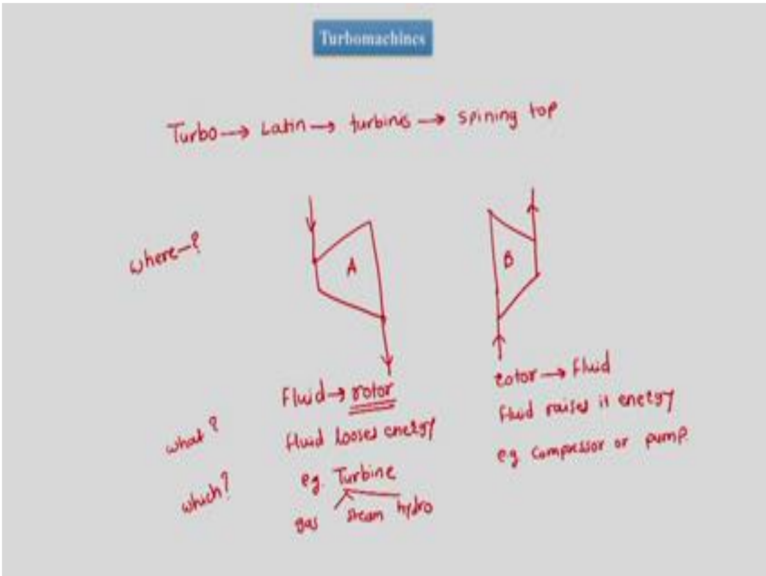

So, the turbo machines whatever we are discussing has a word which is turbo and then this word turbo has latin origin which means turbinis and this turbinis means whirling or spinning top. So, if something is rotating and that something which is rotating for our case are the engine components. But the word here turbo means a rotating top. Now from here we are going to deal with the machines which have rotating components.

And those machines depends upon their interaction have different types. So, what basically are the machines which are getting dealt by us. Basically we have seen that thermodynamics deals with energy interaction of the system with the surrounding. So, where there is this energy coming from or where is this energy going. So, now our system will be something like this where fluid is entering here and fluid is leaving here or our system would be like this where we have fluid which is entering here and which is leaving from here.

So, these two are our open systems where fluid is entering and fluid is leaving. So, say that this is system A and this is system B. Now if we say that in the system A where is this energy interaction taking place. So, suppose energy is going from the fluid to the rotor here since we know terminus means rotating or whirling or spinning object. So, the energy interaction is taking place between fluid and the rotor.

So if energy is taken from the fluid to the rotor and in this phase what will happen to the fluid then fluid losses fluid loses energy and in other case what where is the energy going from we will say that suppose system B has energy which is coming from the rotor to the fluid energy is going from the rotor to the fluid and in this case fluid rises its energy. So, what and where these things are answered than which then which are the components which deal with this energy interaction.

So, system A where fluid loses its energy since it gives this energy to the rotor example is turbine and this turbine can be gas turbine, this turbine can be steam turbine, this turbine can be hydro turbine. And other where fluid takes the energy from the rotor example is compressor or pump. So, these are the two basic distinctions between the turbo machines also turbo machine will either take the energy from the fluid or give the energy to the fluid. So, let us start classifying the turbo machines.

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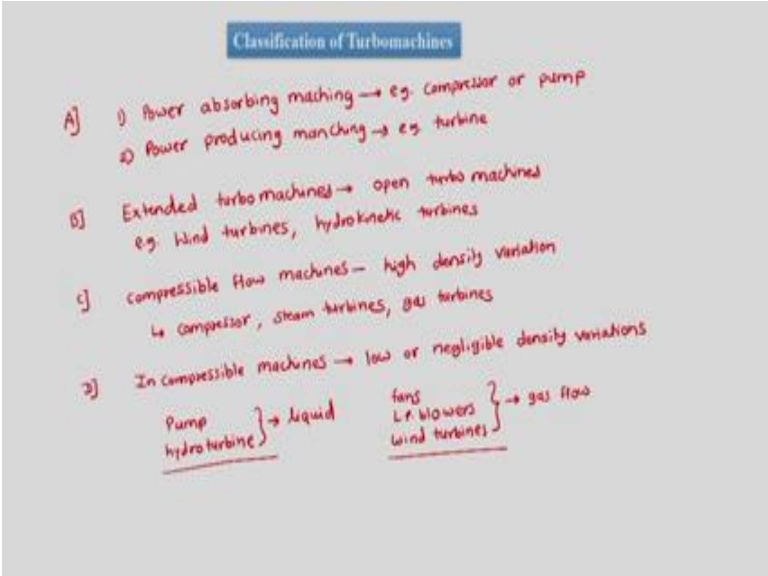

So classification of the turbo machine at the gross would be like we have one a we have first as power absorbing machines. Basically in the power absorbing machines we have fluid which is taking energy from the rotor and we know that example is compressor or pump and second is power producing machines. And in this machines we know that fluid is losing its energy to the rotor and the example is turbine and as what we said they can be any turbine.

Then we can grossly define the turbo machines again as extended turbo machines. These turbo machines do not have any cover or shroud or any enclosure. So, as what we see in case of the wind turbines across the roadside or in the wind farms those wind turbines are open to the atmosphere completely. So, such turbo machines which are open without shrouds without covers are called as the extended turbo machines.

So, these are basically open turbo machines and the example for this turbo machine is wind turbines and there is one more which is called as hydro kinetic turbines which are similar to the wind turbines except for the point that they are kept into the river which will extract the energy from the flowing water without construction of any dam. Then third see in the classification we have compressible flow machines.

From the basics of fluid mechanics we know that the flow is said to be compressible if there is sufficient amount of density change during the flow process. So, if here is sufficient amount of density change which is guarded as around 5% in terms of percentage change in density or if we want to classify in terms of mach number. Then if mach number of the flow is more than 0.3 then flow is said to be compressible.

So the machines which deal with high speed flows or which encounter large density variation, so high density variation are called as compressible flow machines and the example is compressor and steam turbines and also gas turbines. So, these machines are called as compressible flow machines. Then D is incompressible flow machines and incompressible flow machines are those which would have low or negligible density variation then such machines are called as incompressible flow machines.

And then there are many which in our daily life we encounter one is pump and hydro turbine. So, this pump and hydro turbine deal with liquid medium and then we have fans maybe our ceiling fan maybe table fan then low-pressure blowers and then we have wind turbines these are incompressible flow machines since they deal with very low velocity but still gas. So, these are the machines where we have gases the working medium.

These are the machines were liquid as the working medium but the density changes and velocities are too low such that we can put them in the bucket of incompressible flow machines.
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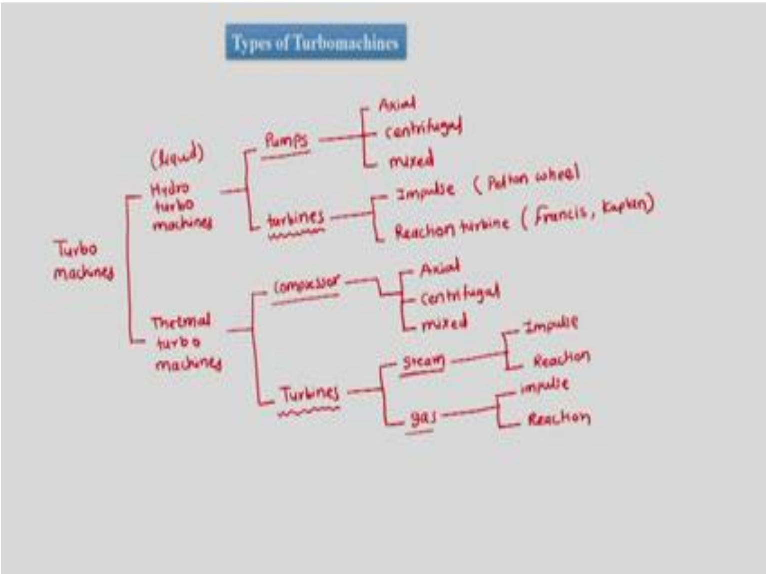

So, based upon that now let us find out what are the types of turbo machines. So, the very first say that we have turbo machines and then we have at gross two types one is hydro turbo machines and other is thermal turbo machines and in hydro turbo machines which deal with basically incompressible material or deal with water in principle or liquids then they are pumps and turbines. Basically hydro turbo machines do not deal with any heat interaction.

So, these are pump and turbines within the pump we have further types as axial pump, a centrifugal pump or we might have a mixed pump. Further in case of turbine we have two more types which is impulse turbine and example is Pelton wheel and we also have reaction turbine and example is Francis turbine and Kaplan turbine. So, these are the two turbines which will deal with reaction turbines for which come under the category of reaction turbine.

But in thermal we have two again types basically which is compressor and turbines then in the compressor we have again axial compressor, we have centrifugal compressor and we have mixed flow compressors. And in the turbine we again have two types but before that depending upon the medium we have either steam turbine or we have gas turbine. And steam turbine again can be impulse type or can be reaction type gas turbine again can be impulse type or reaction type.

So, as what we can see the working medium if it is liquid then it will be classified into two categories one is work absorbing machine and one is work producing machine. So, work absorbing machine is pump producing machine is turbine and they have their own category. So, thermal turbo machines which will deal with large of a density variation then those again will have work absorbing machines and work producing machines.

So, the work producing machine depending upon their working medium they again can deal with steam or they can deal with gas. So, basically here the working medium is getting changed so these are the types of turbo machines in general.

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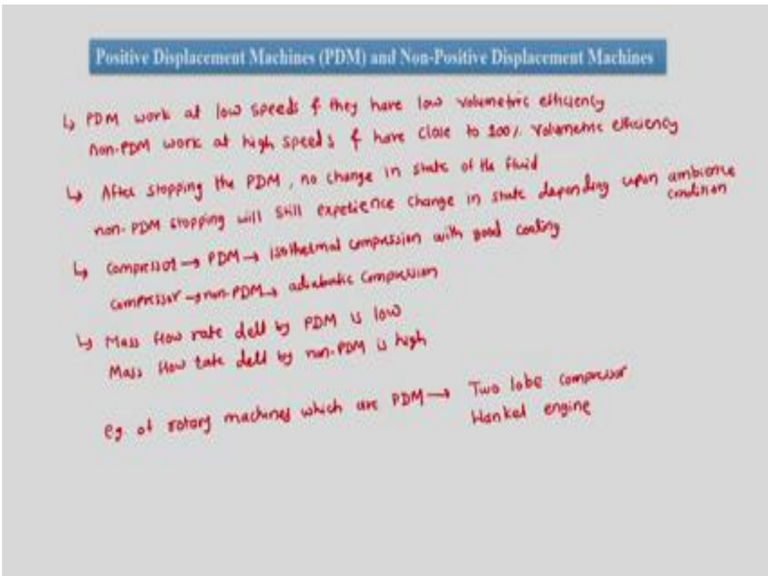

But then as what we say so the turbo machines is one class of machines and the complimentary machines to those is positive displacement machines. So, as what we know the reciprocating machines are generally said as positive displacement machines. The positive-displacement machines there is one major concern with those positive-displacement machines to design is that flow should have one-way entry and one way exit.

So, there is only one path in which flow will go flow cannot take the reverse, so such machines are called as positive displacement machines in general. And it constitutionally happens for the reciprocating machines so reciprocating IC engine or reciprocating pump reciprocating compressor they turn out to be the positive displacement machines. Turbo machines do not come under the category which we are basically going to deal with the those turbo machines do not come under the category of positive displacement machines.

However some rotary machines are still positive displacement. Now we will try to see what is the difference between positive displacement machine and the non-positive displacement machine? We are not saying the difference between positive displacement and rotary or turbo machines and there are some turbo machines which are positive displacement. So, first difference between positive displacement and non-positive displacement is that the positive displacement machines work at low speed and they have low volumetric efficiency.

However non positive displacement machines can work at high speeds and they have close to 100% volumetric efficiency. So, non PDM work at high speeds and have close to 100% volumetric efficiency. Then second point is if we completely insulate a positive displacement machine then in that case if we stop the positive displacement machine which is completely insulated. So, after stopping the positive displacement machine we have no change in the state we mean thermodynamic state of the fluid.

But in case of non PDM if at all we stop the Machine non PDM stopping will still experience change in state depending upon the ambience condition. So, it is no guarantee that we will have a positive displacement machine upon stopping would have same state of the fluid. So, in case of compressor or in case of the IC engine where we are having expansion then in such case if we have complete cooling then as in case of compressor PDM can achieve isothermal compression with good cooling.

Similarly in case of compressor non PDM generally have adiabatic compression. So, the process of compression invariantly is adiabatic in case of non PDM or our rotary machines and then if we implement good cooling system then the compressors which are reciprocating compressors can lead to the isothermal compression. The mass flow rate dealt by PDM is low while the mass flow-rate dealt by non PDM is high.

And these 4 are the major differences between the PDM and non PDM. So, the question remains what are the rotary machines which are still PDM. So, example of rotary machines which are PDM and then the example is two lobe compressor or Wankel engine so these two machines are basically rotary machines but still they execute the flow process such that these machines are basically the positive displacement machines.

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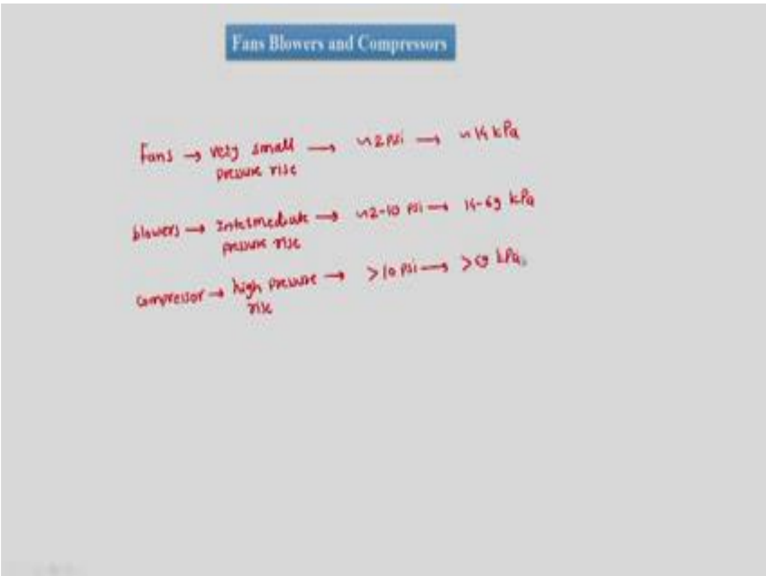

Now having said this we will move ahead and we will see that as what we have seen fans, blowers and compressors all the three are work absorbing machines. So, they raise the energy of the fluid which will be taken from the rotor. Practically fans blowers and compressors they raise the pressure of the fluid. So, all the three entities raise the pressure of the fluid so what is the distinction between them.

So fans as what we know the fans can be a ceiling fan can be a table fan further fans are there in aircraft engines also as we know there is a name called turbofan engine. So, there are fans many a places so the fan basically leads with a small pressure rise very small pressure rise and that pressure rise is of the order of 2 psi or around 14 kPa flow across a fan you try the pressure which is very small in the mount. Then we have blowers, blowers have intermediate pressure rise and blower’s pressure rise is around 2 to 10 psi or it is around 14 to 69 kPa.

And then we have compressors which are for high pressure rise and they give a pressure rise which is more than 10 psi or more than 69 kPa. So, the turbo machines fans blowers and compressor which are work absorbing turbo machines and this turbo machines actually produce the pressure rise and that pressure rise based upon that pressure we can categorize them. We can classify them into 3 different categories as fan, blowers or compressors.

Then we will see the next point where we have seen that a gas turbine is comprised of two major components which are turbines and compressors or these two are the again machines which we have seen that turbine is a work producing machine and compressor is work absorbing machine. But internally these two machines again have two components.

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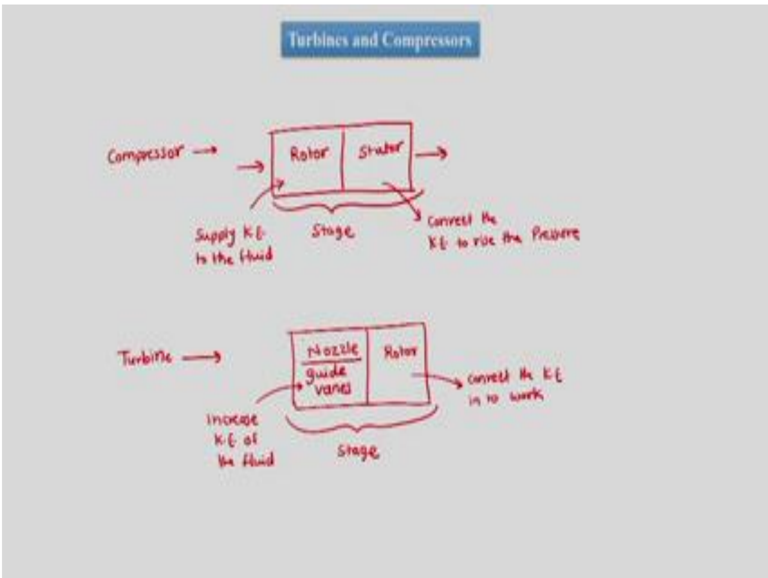

So, let us see what is compressor comprised of. Compressor is comprised of two parts one is called as rotor another is called as stator. So, a flow in compressor will first experience a rotor and then experience the stator then this is called as a stage a combination of rotor and stator is called as a stage. So, if there is a multi-stage compressor then there are multiple pairs of rotors and stators. So, in one stage we have rotor and then we have stator.

So, the job of the rotor is to supply necessary kinetic energy to the fluid this is the place where fluid will absorb the work from the rotor and job of the stator is to convert the kinetic energy to rise the pressure. So, these two constituents will make one stage of a compressor. In case of turbine we have same two components but just placed in reverse order where we have first called a stator which is called here as nozzle or guide vanes this is the first compartment and then we have rotor.

So, the nozzle and guide vanes together will constitute one stage of a turbine. As described nozzle first increases kinetic energy of the fluid. But this is a stator, so the stator is a duct that act basically has some arrangement which will improve or increase the kinetic energy of the flow at the expense of its own enthalpy and then we have rotor and the job of the rotor is to convert the kinetic energy into work.

So, this is the part where it is producing the work this is the part where fluid will lose its energy and will be given to the rotor. So, these are the two components which are constituting one turbine and if we have a multi stage turbine then there are multiple rotor and nozzle rotor combinations or pairs arranged in a specific manner. Having said this we have said about one more thing that there can be an axial compressor there can be radial compressor or there can be an axial turbine or there can a radial turbine.

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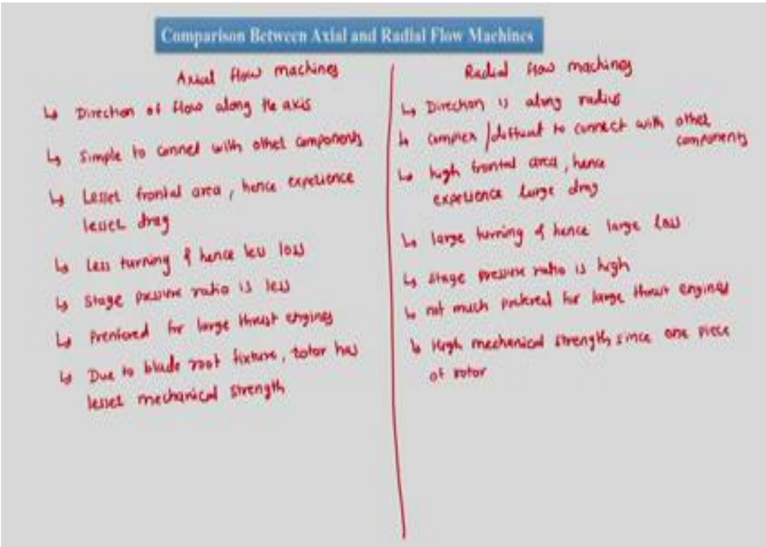

So, what is the comparison between axial and radial turbines. So, let us see that so first see that we have axial turbine here, axial flow machines in general and we have radial flow machines and we will say give the difference among them as the name suggests axial-flow machines will have direction of flow along the axis is the major direction of flow and here major direction of flow is along the radius. So, it is the axis of rotation where the flow is taking place is not aligned and it is going in the normal direction to the axis of rotation.

But in the axial flow machines flow and axis of rotation are in the same direction. So, this is simple to connect with other components and this is complex or difficult to connect with other components then the difference is axial-flow machines have lesser frontal area hence experience lesser drag. But radial flow machines have high frontal area so hence experience large drag.

Basically we are concerned with the flight and the flight engine or aircraft engine so in that case we are believing upon a propulsion system which should experience a lesser drag on its own so the propulsion system itself should experience the lesser drag. So, in such case the lesser frontal area of axial machines would have better preference since they experience lesser drag. In this case since the flow is axial it has less turning and hence less loss.

But there is large turning of the flow since the approach of flow is invariantly axial but the motion within the machine is radial. So, it has to experience large turning and hence flow will experience large loss then but the problem is in one stage pressure ratio is less in one stage of a compressor which is axial compressor experience would produce lesser pressure ratio. However in case of radial compressor or centrifugal compressor stage pressure ratio is high it is around 4 to 8.

Where in case of radial machine but in case of axial machine it is around 1.2 to 1.6 but these machines since can handle large mass flow rate they have preferences they are preferred for large thrust engines and then they are not much preferred for large thrust engines. while constituting the axial flow machines we have a shaft on which the rotor blades will be mounted. So, we have to make a root of the rotor blade and that will be fixed upon the shaft.

So due to blade root fixture, rotor has lesser mechanical strength while in case of radial flow machines let us say compressor so centrifugal compressors rotor or impeller is fabricated in a single piece so it has higher mechanical strength high mechanical strength. Since we have one piece of rotor, so, these are the at gross major differences between axial and radial flow machines.

So in this class what we have seen is what do you mean by turbo machine how to classify different turbo machines based upon their types based upon their working medium based upon their interaction or flow path. And then we have seen the; what are the components of basic turbo machines like compressor and turbine. And then we have seen what is the basic difference between the axial and radial flow machines we will see next things in the next class, thank you.