Applied Thermodynamics
Dr. Pranab Kumar Mondal
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Steam Power System
Lecture - 12
Impulse Steam Turbine: Velocity Diagrams, Work Transfer, Blade Efficiency

We shall start our discussion today on the Applied Thermodynamics and today, we shall discuss about an important component of the Steam Power Plant, the Steam Turbine. Now, today we will see that the different types of steam turbines which are commonly used in thermal power plant. And then, for the operation of steam turbine, few important performance indexing terms like work transfer, blade efficiency we will be discussing.

And to discuss those, we need to know the velocity triangles that you have probably studied in the context of fluid machines, that velocity triangles at the inlet and outlet is very important to understand the efficiency, which will be obtaining from that particular device. Now before I go to discuss about the steam turbine part, I could not complete close type feedwater heater.

In the context of regenerative cycle, we have discussed about open type feed water heater and we have seen that by having special arrangement like feed water heater, we can reach the efficiency closer to the ideal Carnot cycle efficiency and though, we have seen that additional cost is involved from the perspective of both installation as well as the operational cost.

But still efficiency can be increased to that of the ideal Carnot cycle efficiency. So, I mean justification should be there that the additional cost involved with such an arrangement should be justified from the perspective of the increment in efficiency that we are looking for.

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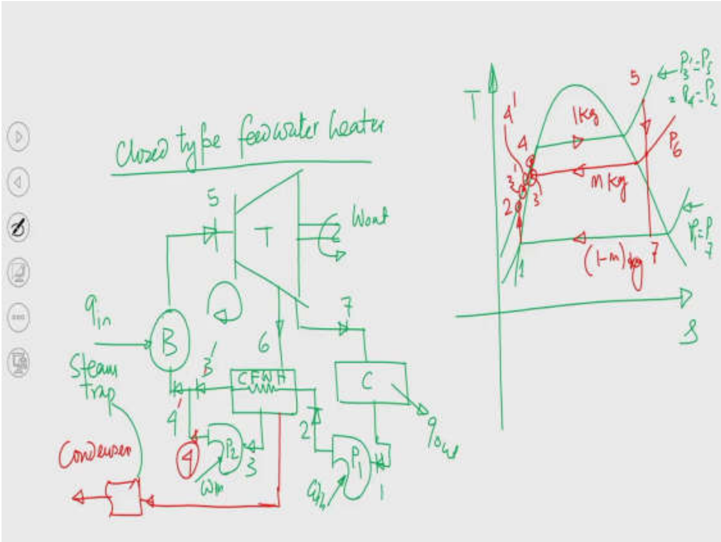

So, today, we will be discussing about closed type feedwater heater. Let me draw the schematic depiction. So, we are having this essential component that is boiler. So, heat is added over here and then, steam which is coming out is taken to the turbine for expansion and this is rotating.

We will be getting W out and you know that there will be one heater that is closed type feedwater heater and some steam will be taken from the turbine or extracted from the turbine and remaining steam will be taken to the condenser. So, this is condenser; wherein, heat will be rejected and finally, the collected condensate will be pumped back to this heater.

And so, this is pump. We need work input and here, idea is that two stream will not be allowed to mix directly together and the water will be pumped to the boiler. Sometimes, it may require one additional pump; again, we need W in. I am keeping the provision of another one special arrangement that is known as steam trap. So, this steam trap is essentially goes to condenser.

Try to understand here, you know that in the previous class, we have seen that the collected condensate is pumped to a device which is open type feedwater heater; wherein, the extracted steam is allowed to mix directly. So, the extracted steam is allowed to mix directly with the condenser that is pumped from the condenser. Here, it is not that type. So, this is open.

But here, you see that condensate will be pumped through a coil and when the condensate is passing through the coil in the special device, steam will be allowed to pass over the coil and because of this heat exchange, the feed water temperature will be increased and it will go to the boiler.

We have discussed that we had additional pump in open feed heater essentially to build up the pressure up to the boiler pressure. Here, second pump may not be required; though I have kept the provision of second pump. But if the pump P_1 can be designed in such a way that the condensate which is collected from the condenser will be pumped through the coil and eventually, it will reach to the boiler.

So, if we design the pump in such a way that the pump will be able to develop up to the boiler pressure, definitely there will be a pressure drop when liquid is passing through this closed coil. But that is what I am telling that someone should design or designer should design the pump accordingly. But another provision is there.

So, when steam is extracted from turbine, the amount of steam that will be extracted again will depend and that we have to calculate. Now, when steam is releasing heat and the feed water will receive heat, upon exchanging heat steam temperature will fall and we may have to pump that steam again to the boiler.

I mean up upon releasing heat, steam will be condensed and that condensate again will be pumped back to the boiler pressure. Definitely, the intermediate pressure is less than the boiler pressure. So, that is why the provision of second pump is there. So, considering the probability of having that the steam get completely condensed upon releasing heat and then, the condensed or condensate will be pumped back to the boiler.

Otherwise, if it is the case that though steam is releasing heat, feedwater temperature will increase; but still we are having kind of two phase mixture right. So, steam is not getting completely condensed. Though steam is releasing heat and that heat will be absorbed by the feedwater, but even after releasing heat, we are getting essentially two phase mixture.

And since pump cannot handle two-phase mixture; in that case, the second pump will not be required. What will be done? In that case, the collected two-phase mixture will be allowed to pass through a special device that is called steam trap. So, I am writing this is known as steam trap.

So, it will trap steam and the liquid part will be taken back to the condenser and since, we are having pump and that liquid will be pumped back to the boiler. So, this is the way by which the regenerative cycle with closed type feedwater heater operates. So, now, let me draw the T s diagram and that will help you to understand.

So, try to understand, as compared to the open type feedwater heater, it is less expensive, if we can design the system properly so that upon releasing heat, maybe steam will not get completely condensed. In that case, two-phase mixture will be taken through this special device that is called steam trap.

And steam will be trapped therein and the liquid part will be taken back to the condenser for pumping to the boiler. But if it is not the case, then probably second pump will be required. If we do not require second pump, then probably you can understand this is less expensive because second pump was essential for the open type feed water heater.

So, try to understand that if I try to compare the regenerative cycle operating with close type feedwater heater, now in that case, designing the close tube coil, additional cost will be involved; maintenance as well as installation cost.

So, though we do not require additional pump, if we can design the system properly; but additional cost will be there because of this special arrangement. For the open type feedwater heater, we have seen that there was no such coil through which feed water is pumped.

So, for the special coil, maintenance cost will be required because you have seen from heat transfer knowledge that when a particular liquid is flowing through a closed coil, then because of the deposition that tube may not function properly after a few years. So, that is why maintenance will be there. So, maintenance cost as well as the installation cost will be there. So, that part is there for this closed type feedwater heater.

But if we cannot design the system properly, so if we need two pumps together, then it will be very much expensive as compared to open type feedwater heater. So, you know that 1 to 2 that is condenser pressure; so, let us draw. So, this is $P_1 = P_7$.

This point is 1, and it is pumped up to the boiler pressure side. So, boiler pressure is 3` and 5`. So, if we try to draw it; so, this is $P`_3 = P_5 = P_4 = P_2$. So, now, certain amount of steam will be taken. So, maybe this is the point 5 and steam will expand isentropically and if we take certain amount of steam say this is the intermediate pressure. So this is P_6.

Now, as I told you that if you design in such a way that the extracted steam will be condensed completely and will be getting saturated liquid at point 3. So, say this is point 3 and this will be pumped back. So, this is point 4. So, if we design in such a way that after releasing heat, steam will be saturated liquid because pump cannot handle two-phase mixture.

So, essentially, you try to understand the state at point 3 should be the saturated liquid. Now, you try to understand that 3, 3` and 4, 4` temperature are almost equal. So, this is saturated liquid. So, a slight increase in temperature will be there because of the frictional heating. So, temperature of 3 and 4 should be equal. Now, I mean the temperature at point at state point 3` and 4` should be slightly higher than temperature 3 and 4.

So, basically though temperature this 3, 3`, 4 and 4` will be equal; but entropy at state point 4 that is at the exit of pump P_2 should be slightly higher than the 3` and 4`. Can you tell me, why the entropy should be higher?

See we are collecting steam, the steam which is extracted from the turbine is having high enthalpy and after releasing heat though it is getting completely condensed; but still the enthalpy is high and it is again pumped backed. So, the entropy at point 4 will be slightly higher than the entropy at point 3` and 4`. So, it is very difficult to demarcate at all these points but you have to understand.

So, temperature at point 4 should be slightly higher than the temperature at 3` and 4`. Since, it collected steam, though it has released heat; but it is very difficult to say that steam will release complete heat. So, since temperature is slight higher, entropy will be slight higher. So, that is why this is the schematic depiction.

Now, if you take m kg of steam, extraction is 1 - m kg of steam and that is 1 kg of steam. So, if you do this energy balance, apply steady flow energy equation to the closed type feed water heater, you will be getting what is the expression of m. Next, I will be discussing about another important component of this cycle that is called the steam power plant.

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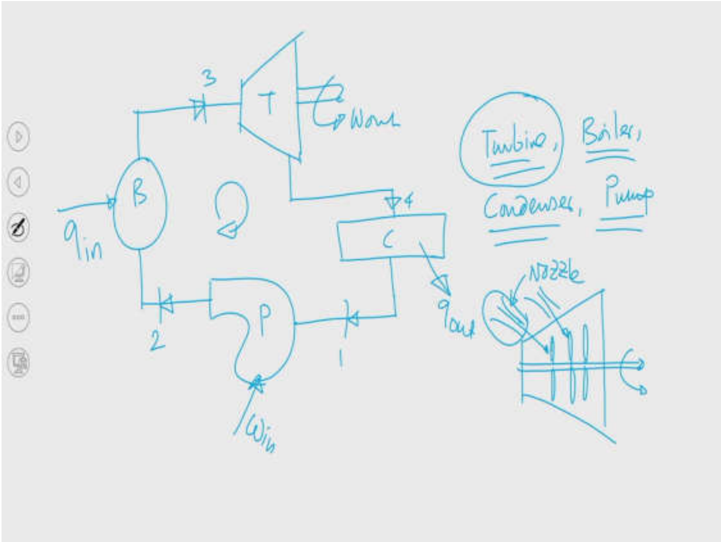

So, if you try to draw the schematic again. So, this is boiler, this is turbine that is W_{out}, this is pump, this is condenser q_{out}. See we have discussed about so many modification. So, this is simple Rankine cycle.

Here pump is there, so, definitely quality of the working fluid will be saturated liquid at state point 1. See though we have shown over here only 4 major components; but to have in a thermal power plant there are so many other minor components which are essential for the smooth and efficient operation of the plant; one component will be steam nozzle.

So, we will start discussing about turbine today. Now, before, let me tell you the steam which is produced in the boiler, that steam will be taken to the turbine and while steam is expanding. It does work on the rotating part of the wheel and from there; we will be getting work output.

As I written over here that is work output. So, the turbine shaft will be connected to the shaft of an alternator, from there we will be getting electricity. So, when steam is expanding inside the turbine, it does work. The steam will not be allowed directly to go into the turbine as it comes from the boiler rather before steam will be allowed to pass through flow nozzles, before it enters into the turbine.

So, you have studied perhaps nozzle; otherwise, in fact, I will discuss in this class. What is the function of steam nozzle? So, steam which is produced inside the boiler will be taken through the flow nozzles so that the velocity of the steam will increase at the cost of the enthalpy drop. So, when steam passes through the nozzle, we need to play with the velocity and pressure.

So, you know that at the reduction of pressure, we need to increase the velocity of the steam. So, when steam passes through the nozzle, velocity will increase as if the steam which is coming out from the nozzle in the form of a jet and we need to increase the kinetic energy of the jet, before it strikes the turbine blade. So, when steam is striking the turbine blade, its momentum will change.

And you have seen you have probably studied in hydraulic turbine that due to the change in momentum direction, if I apply Newton's second law, we will be getting thrust. Because of this high velocity jet which is having high kinetic energy to be precise, there will be a change in momentum and change in momentum will produce work and the wheel will rotate.

So, this is basically the concept. Though we will be discussing about the flow nozzle, so try to understand the nozzles are essential and we shall discuss about this particular component because our objective should be to increase the kinetic energy of steam before it enters into the turbine.

Now, for the turbine, the high kinetic energy will be absorbed by the wheel and it will rotate. So, the energy of exit steam will be absorbed by the turbine wheel and a part of the energy will definitely will not be absorbed. But we can understand that there is energy transfer.

So, energy will be transferred from the incoming jet to increase the speed of the shaft. So, depending on the types of blades, the turbines are classified into two categories.

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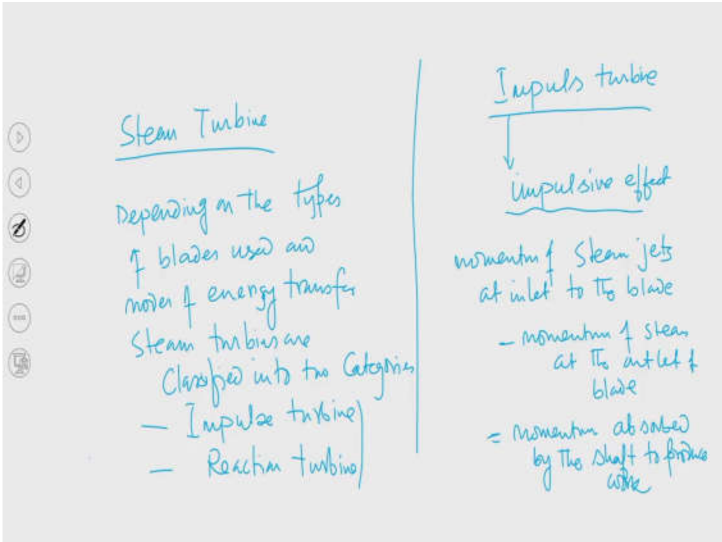

Now, here working fluid is steam, so that is the steam turbine. So, depending on the types of blades used and modes of energy transfer, steam turbine are classified into two broad categories; 1) impulse turbine, 2) reaction turbine.

Today, we shall discuss about impulse turbine. So, the name impulse is coming from the impulsive effect. So, when steam coming out from the nozzle is striking the turbine blade, then impulsive effect will be there and because of this impulsive effect, the kinetic energy will be absorbed by the wheel/shaft of the turbine and we will be getting work output.

So, what is impulsive effect? As I told you there will be momentum change because of this momentum change, turbine blades will start rotating. So, momentum of steam jets at inlet to the blade - momentum of steam at the outlet of the blade = momentum absorbed by the shaft to produce work.

So, high velocity jet is striking the blades which are mounted on the shaft of the wheel. Now, as the high velocity jet is striking, so there will be an impulsive effect.

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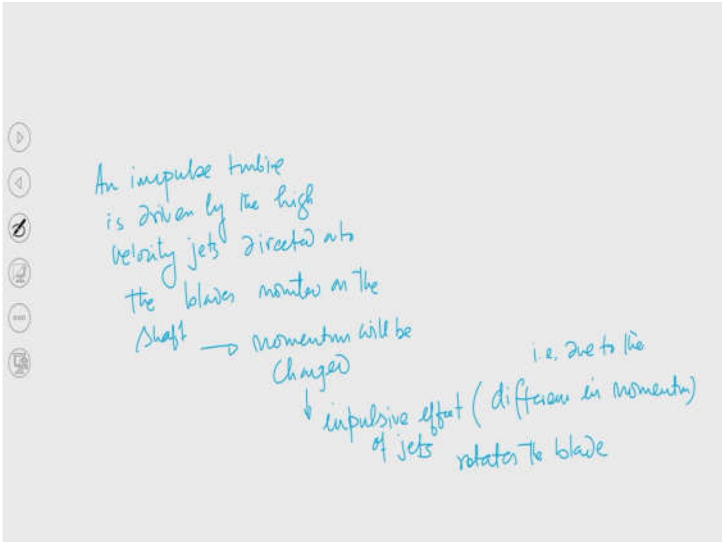

So, an impulse turbine is driven by the high velocity jets directed on to the blades mounted on the shaft. Now, when the high velocity jet is striking the blades which are mounted on the shaft, the direction will be changed, direction of the steam jet will change, so momentum will be exchanged.

So, when there is a change in momentum, as I have written over here that momentum of the steam at the inlet to blade and outlet to the blade. So, due to the difference in momentum, an impulsive effect is produced.

Since, the turbine essentially works on the principle of this momentum difference, the impulsive effect is produced and that is why these turbines are called impulsive turbine.

So, this is the turbine in which the work that is produced by virtue of the momentum difference and this momentum deference leads to the impulsive effect and that is why the name impulsive turbine is there.

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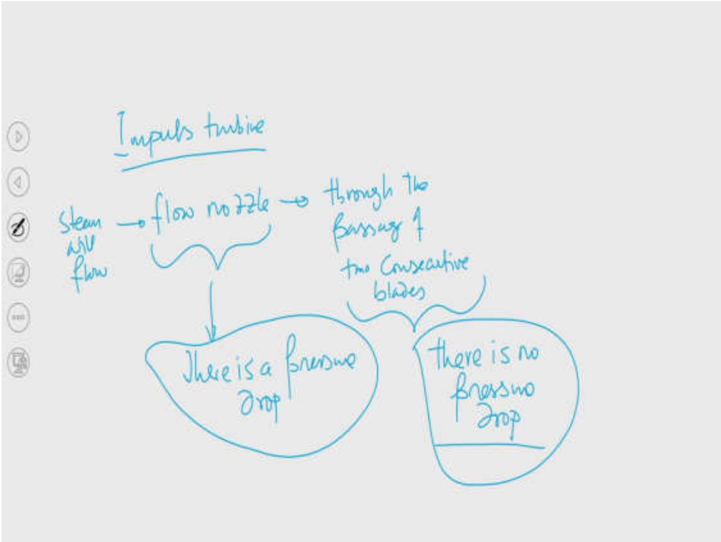

So, now, we shall discuss that in impulse turbine, as I told there will be a set of nozzles. A set of nozzles will be required essentially to create steam jet. So, steam which is coming out from the turbine will be taken or will be allowed to pass through the flow nozzles; wherein by reducing the pressure the velocity of the steam will be increased. Thus high jet will strike the blade and there will be momentum change and we will be getting work output.

So, a set of flow nozzles will be there. Say if we have one nozzle over here and steam is striking this blade. See after striking, steam will pass through the passes between two consecutive blades right.

So, we can understand there will be a few blades, a few nozzles through which steam will be allowed to pass before it enters into the turbine; after striking, steam will come out from the turbine and steam will flow through the passage between two consecutive blades.

So, essentially, what we can understand in impulse turbine flow nozzle will be there. So, steam will flow through flow nozzle, then through the passage of two consecutive blades. So, steam will come out from the boiler, it will be taken through the flow nozzle essential to increase kinetic energy.

After doing some work, the steam in the form of jet will strike the blades and then after impinging, it will come out from the turbine and after impinging, it will flow through the passage between two consecutive blades.

So, for the impulse turbine when steam is passing through the flow nozzle, there is a pressure drop because at the cost of this reduction in the pressure, we are getting kinetic energy; velocity will increase and that is what our objective is.

So, objective is to increase the kinetic energy of steam as it comes out from the nozzle and the increase in velocity will be at the cost of the reduction in the pressure. So, pressure drop will be there. But when steam is passing through the passage between two consecutive blades, there is no pressure drop.

So, when there is no pressure drop, what will be the velocity? And that we need to understand through the velocity diagram. So, by drawing the velocity triangles, we will try to understand the change in pressure, velocity of steam as it passes through the flow nozzle as well as through the passage between two consecutive blades and thereafter, we will try to find out what is the magnitude of work that we are expecting.

So, what is the amount of work that will be transferred to the shaft of the turbine and from there, we will try to quantify the blade efficiency. And those part, we will be discussing in the next class.

Thank you.