Aircraft Propulsion

Prof. Vinayak N. Kulkarni

Department of Mechanical Engineering
Indian Institute of Technology-Guwahati

Lecture-35
Radial Turbines

Welcome to the class. Today, we are going to talk about radial turbines. As the name suggests, these are the radial flow machines where the dominant direction of the flow is in the radial direction or the flow flows in the direction of radius of the turbine. So, the configuration of this turbine is similar to that of compressor which is centrifugal compressor. In the centrifugal compressor we had seen that the flow enters near the axis and then goes outward in the volute casing.

That was the radial flow compressor or centrifugal compressor, but in the case of radial flow turbine there are two options; one is in inward flow or outward flow. The most common what we can see is inward flow turbine where flow would come from the outer part of the radius and goes towards the axis of the turbine. Let us see the schematic and basics of radial flow turbine.

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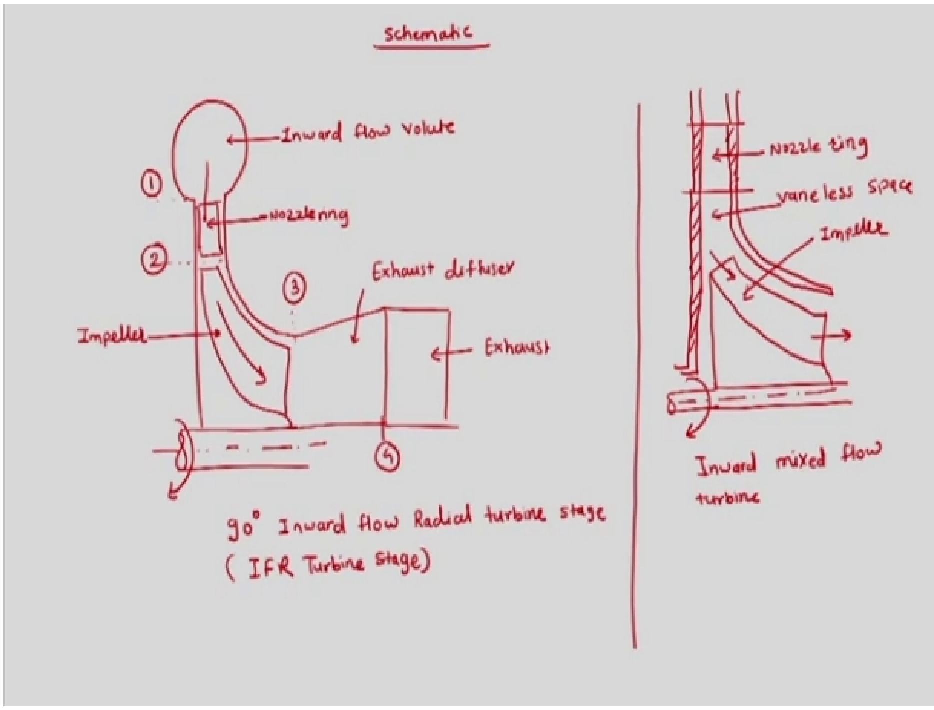
So, this part is exhaust diffuser and second is exhaust, this is exhaust section. The shaft would rotate and then the flow is coming in this direction. As expected, we should give thermodynamic states. This is state 1 at the entry to the nozzle, state 2 at the exit of the nozzle, state 3 at the exit of the impeller, so this is impeller, and state 4 is at the exit of the exhaust diffuser.

So, this is called as 90-degree inward flow radial turbine stage. This is also called as inward flow radial turbine stage. So, this is the schematic of the inward flow radial, but apart from inward there can be a mixed flow radial turbine where we will plot schematic from the nozzle.



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This is the nozzle ring. Suppose, this is nozzle ring, and after the nozzle ring there would be some space which is vaneless space, and then there would be impeller. So, this is nozzle ring, this is impeller, and then this is vaneless space, this is shaft which is rotated.

Here, while coming flow does not enter radially, so this is called as inward but mixed flow. Direction of velocity is partially axial also flow turbine. Having said this, we can then see what is the thermodynamic process in the turbine.

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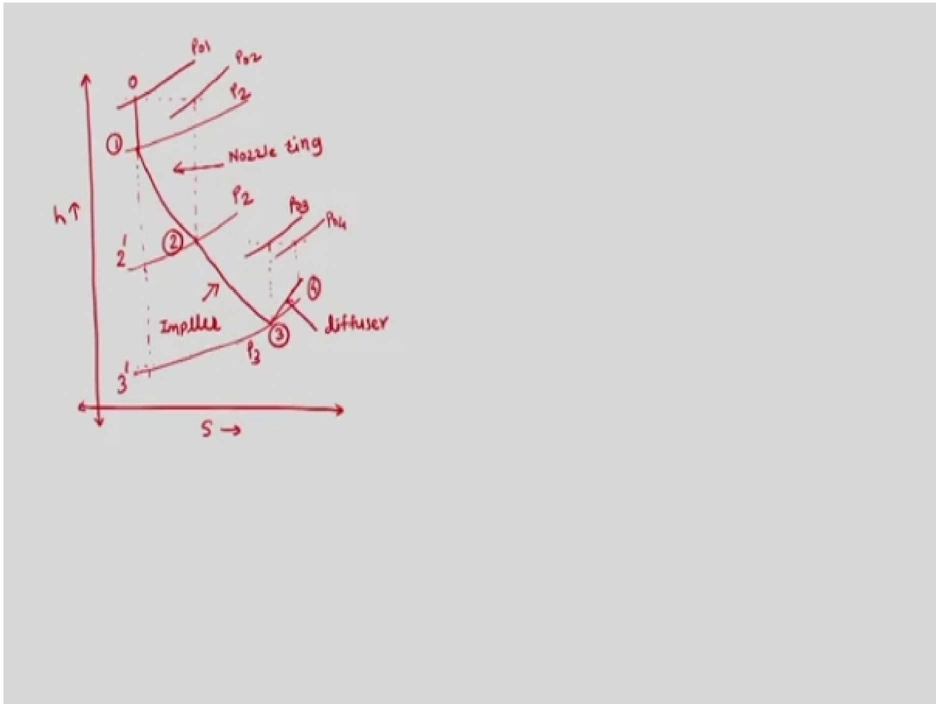
Now, having said this, in the impeller it will continue and then reach the state which is P_3 which isentropically it would have reached, then it would have reached to $3^{'}$. And then, for case 3, we have then this as the P_{03} which is total condition, but after 3 it is having diffusion in the exhaust diffuser. So, this is state 4 and for state 4 we would have diffusion. So, no work interaction process.



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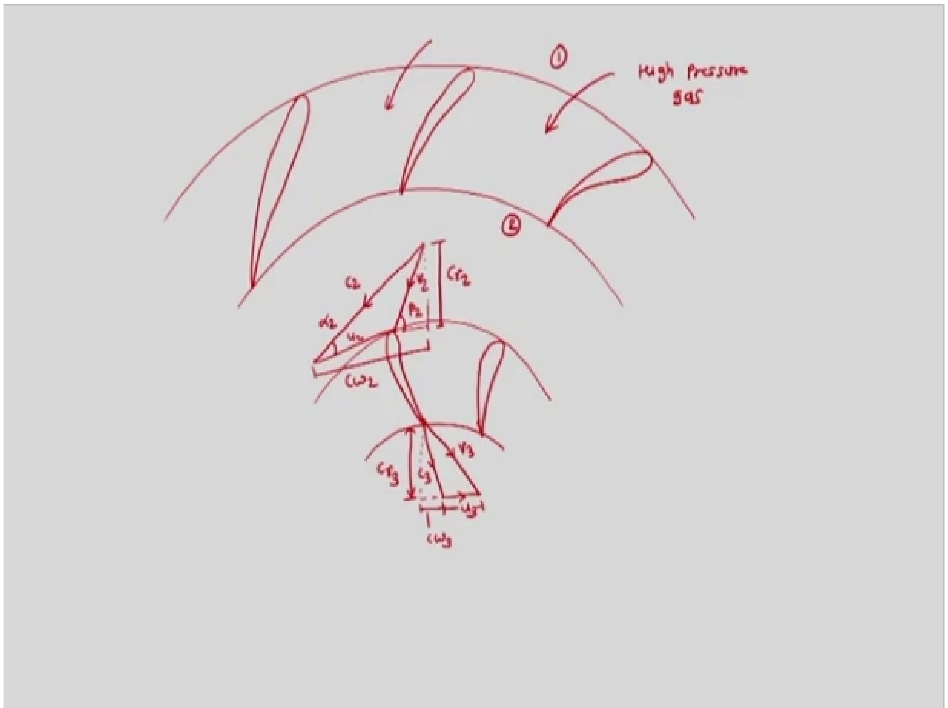
So, this is P_{04} and here we end the thermodynamic process for the radial flow turbine on h-s chart. So, 1 to 2 corresponds to nozzle ring, 2 to 3 corresponds to impeller and 3 to 4 corresponds to diffuser. So, this is how the total flow will take place in the case of radial flow turbine.

(refer time: 09:23). Now, let us plot the flow or velocity triangle for the radial flow turbine. In case of radial flow turbine we would have first the nozzle ring. So, this would be the flow through the nozzle ring where we will have some vents on the nozzle which would accelerate the flow inward. So, this is the direction of high pressure gas which is entering into the nozzle ring, then it will enter into the impeller.

Now, let us consider this impeller where we would have tangential velocity like this and flow is entering at tangential direction which is this. So, this is state 1, this is state 2. So, this is V_2 and this is u_2. But the absolute velocity is like this, so this is C_2. Having said this, this will be the radial velocity which is C_{r2} and hence this complete distance will be C_{w2} and hence angle of absolute velocity is α_2, angle of relative velocity is β_2.

Having said this, the flow would go out tangentially with velocity V_3, but it will have absolute velocity which is C_3 and tangential velocity at this point can be plotted over here and this is u_3 and this is C_3. So, we can plot two quantities, one is this which is C_{w3} and the other is this which is C_{r3} and this is u_3. So, this is the schematic of the flow pattern and the velocity triangles for the special case of radial flow turbine. Within that we are going to see some



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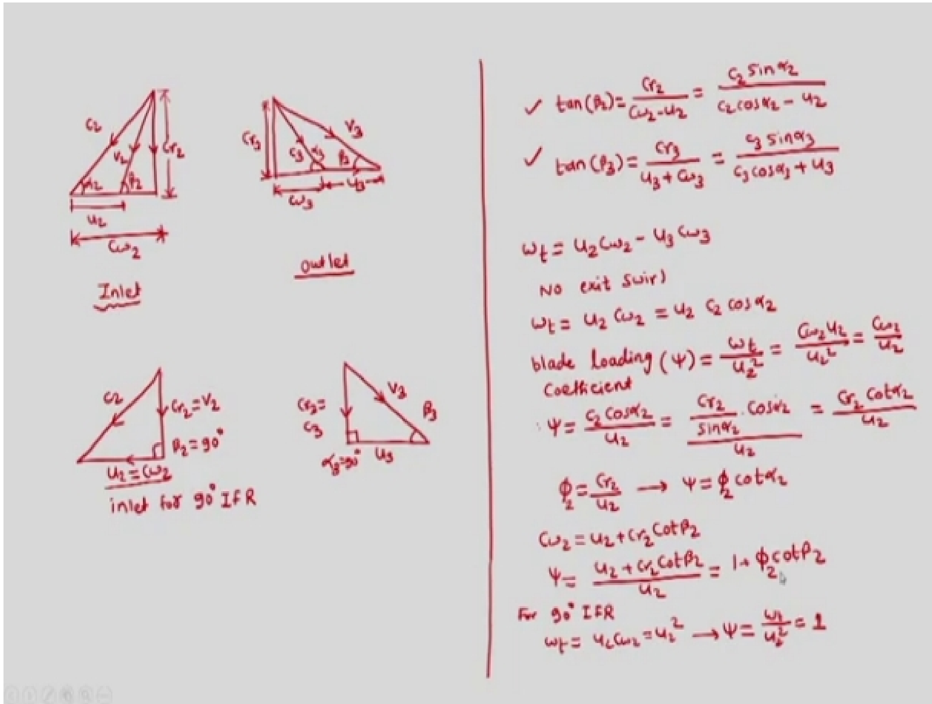
more special cases.

(refer time: 12:45). Let us see that these are the velocity triangles where we had seen inward velocity triangle is like this where this was C_2, this was V_2, this was C_{r2}, this is u_2, α_2, β_2, and then this would be C_{w2}. This is inlet velocity triangle. For outlet velocity triangle we will have this as u_3, this as C_3, this is V_3, this small component is C_{w3}, this is C_{r3}. So, we have α_3 and β_3.

Using this we can actually have now outlet velocity triangle, but these two triangles for a specific case of 90-degree inward flow turbine would be like this where we will have a special inward flow turbine triangle at the inlet for 90-degree inward flow radial turbine where this is C_2 and we have $C_{r2} = V_2$ and we have $u_2 = C_{w2}$. Since here $\beta_2 = 90°$.

For the outlet same turbine would have triangle like this where this is u_3. We have $C_{r3} = C_3$ and this is V_3. So, $\alpha_3 = 90°$ and this is β_3. So, these are the special cases of velocity triangle. Having said this, we can now write down different expressions. If we are interested to find out tan β_2 we can get it from this velocity triangle as $\frac{C_{r2}}{C_{w2}-u_2}$, where C_{r2} can be written as $\frac{C_2 sin\alpha_2}{C_2 cos\alpha_2 - u_2}$.

Similarly, tan $\beta_3 = \frac{C_{r3}}{u_3+C_{w3}}$ which is $\frac{C_3 sin\alpha_3}{C_3 cos\alpha_3 - u_3}$. This is how we can find out given nozzle



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angles what are the blade angles. So, work done by the turbine, as we know, it is u_2C_{w2} - u_3C_{w3} for the special case of no exit swirl. We have turbine work is equal to u_2C_{w2}. So, we can write $C_{w2}C_2\ \alpha_2$.

This is the formula for work done. So, we can write the expression for blade loading coefficient which we had always defined as ψ and that is $\frac{W_t}{u_2^2}$. So, it is $\frac{C_{w2}u_2}{u_2^2}$. So, it is $\frac{C_{w2}}{u_2}$, but we can define C_{w2} as $\frac{C_2 cos\alpha_2}{u_2}$. Further, C_2 can be written in terms of C_r. So, it becomes $\frac{\frac{C_{r2}}{sin\alpha_2}.cos\alpha_2}{u_2}$.

So, cos divided by sin, so it is $\frac{C_{r2}cot\alpha_2}{u_2}$ where we can define a term ϕ which is equal to $\frac{C_{r2}}{u_2}$. So, we get ψ is equal to $\phi_2$cot α_2. But if we define C_{w2} = u_2 + C_{r2}cot β_2, if we define it in this way and then write down ψ is equal to $\frac{u_2+C_{r2}cot\beta_2}{u_2}$, then we get 1 + $\phi_2$cot β_2 as ψ. Having said this, we can get a special case for 90 degrees inward flow radial turbine.

We have W_t = u_2 C_{w2}, but we know C_{w2} = u_2. So, it is u_2^2. Now if we define ψ which is $\frac{C_{w2}}{u_2}$ which is rather $\frac{W_t}{u_2^2}$. So, this becomes 1. This is the term which is flow coefficient which is ϕ_2. So, this is ϕ_2. So, we get loading coefficient as 1 for radial case. Now, let us define the efficiency which is stage efficiency.

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Then, we can define stage efficiency as $\frac{W_t}{W_t'}$ where W_t is $\frac{(1+\phi_2 cot \alpha_2).u_2^2}{C_p(T_{01}-T_{03})}$. We can take T_{01} common. So, we will have $\frac{1+\phi_2 cot \alpha_2).u_2^2}{C_p T_{01}(1-\frac{T_{03}}{T_{01}})}$. We can define the ratio of temperatures in terms of ratio of pressures, cot β_2.

Then, we can get the denominator C_pT_{01} $\left[1-\left(\frac{P_{03}}{P_{01}}\right)^{\frac{\gamma-1}{\gamma}}\right]$. So, this is the stage efficiency which we can find out. Then, we can work to find out degree of reaction. So, if we see degree of reaction we have always defined it as T_2 - T_3 which is enthalpy corresponding to enthalpy drop in the rotor divided by total enthalpy drop in the stage.

We know that enthalpy drop in the rotor can be said as work done minus absolute velocity change divided by total enthalpy drop in the stage. So, λ = 1 - $\frac{C_2^2-C_3^2}{2C_{w2}u_2}$. So, lambda is equal to this, but we can also know this enthalpy drop in the rotor can as well be written from the Euler turbomachinery equation as $\frac{\frac{1}{2}(u_2^2-u_3^2)+\frac{1}{2}(V_3^2-V_2^2)}{C_{w2}u_2}$.

One half can be brought down, so we get $\frac{(u_2^2-u_3^2)+(V_3^2-V_2^2)}{2C_{w2}u_2}$. Having said this, this can be a different derivation for the radial flow turbine and this is how we can relate the flow which is flowing through the radial flow turbine. Here, we end the discussion on radial flow turbine. We will see the examples related to turbines in one of the classes. Thank you