Fluid Machines.
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Lecture-16.
Axial Flow Turbine.

Good morning and welcome you all to this session of course on fluid machines. In the earlier few sessions we were discussing about the radial flow reaction turbine which is named as Francis turbine after the name of the American engineer who contributed a lot to its development. So in Francis turbine we have seen that it is a radial inward flow turbine. Flow at the inlet is in the, mostly the radial direction. It has got radial and tangential component of velocity.

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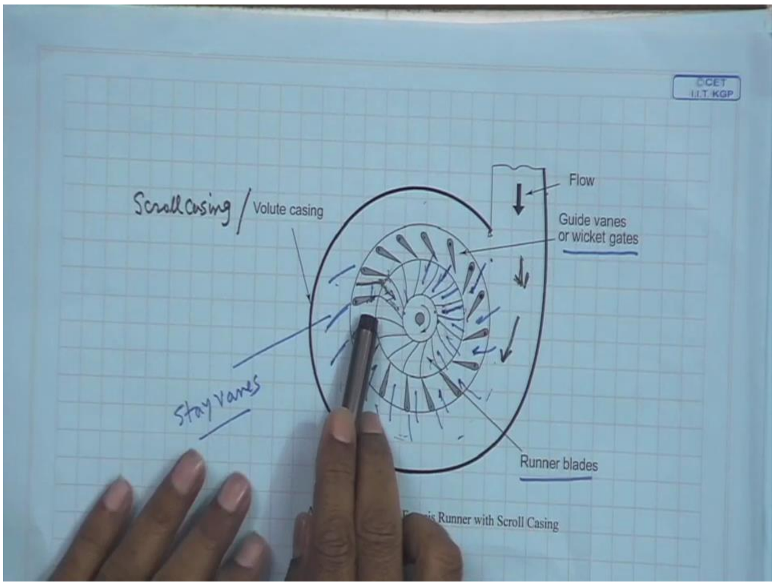

And the bulk flow is in the radial direction, radial inward and while it is coming out, it is purely radial and the tangential component is kept almost to 0 to have the minimum kinetic energy at the outlet. Now one thing has to be remembered, please have a look at this turbine. That, this is the typical runner blade or runner of the turbine and you see when it flows through this, this has a radial and tangential component of velocity at inlet. When it comes outward, then it has purely radial velocity which is turned 90 degree in the axial direction, while in turn seen to the draft tube.

Now one important thing that we already discussed also is that this reaction turbine is efficient at high, low head. That means if it has to run efficiently at a lower head or a higher specific speed, then what happens, to develop a considerable power, it has to admit a large amount of flow into the turbine, that means the flow rate has to be high if the head available in the less and it has to work efficiently. But at the same time it is already appreciated that the velocity of discharge at the end has to be low.

That means the velocity at inlet to the draft tube has to be low to avoid cavitation so that the pressure at inlet to the draft tube does not fall below the vapour pressure of the working fluid, that is water at the working temperature. So to maintain this criteria, that 2 criteria that velocity low at the discharge and accommodating high flow rate, what is required is a cross-sectional area of the flow should be large, which is difficult to maintain in a purely radial flow turbine.

Moreover the cross-sectional area in the direction of flow has to decrease to decrease the static pressure of the working fluid. Because you know in reaction turbine, the static pressure, that is a drop in the static pressure, drop in the static head for the fluid as it flows through the blades or the rotor blades. So therefore in this type of converging passage in purely radial flow at the outlet, it is difficult to accommodate high flow rate with maintaining low velocity. This has evolved the concept of axial flow turbine.

That means if we consider the turbine blades or the blades such that while the flow, the flow enters in the radial direction, it has got mostly the radial and the tangential component of velocity. But while flowing through the runner, these radial velocities gradually change to an axial direction, that is flow direction is gradually change to an axial direction. And finally at the outlet, if the entire flow comes axially, that means entire velocity of flow or the absolute velocity becomes axial direction, then they can accommodate more area.

That means if the blades are twisted like that to make the outlet axial, outlet cross-sectional area normal to the axial direction, it can provide more area and to accommodate more flow. And this gives rise to the concept of axial flow turbine. Actually this is known as mixed flow turbine where the inlet is radial and inlet velocity components have both radial one and the tangential one while flowing through it, throwing through the runner blade, sorry, flowing through the runner blade, the direction of flow changes gradually from radial to axial.

And while it comes out of the runner, runner exit, substantial part of the velocity component is, that means the essential part of the velocity component is in axial direction or purely axial. This type of runner is known as mixed runner. While it is entirely axial flow, that means inlet is also axial, the fluid is directed by the guide blades in such a way that the flow already becomes in the axial direction. And through the entire runner blade, it flows along the axial direction and comes, that means if it is a horizontal turbine, the flow changes like this and it flows along the axial direction, that is in the vertical direction which is the axial direction.

Direction of the axis of the rotating shaft. So is type of flow is, turbine is known as axial flow turbine and this can accommodate very high value of cross-sectional area of flow, that is the area of flow in the horizontal plane perpendicular to the axial direction. And can accommodate large quantity of liquid flow rate, mass flow rate of liquid and can work more efficiently at a very small head or high specific speed. So this is the basic concept, originating concept of the axial flow turbines.

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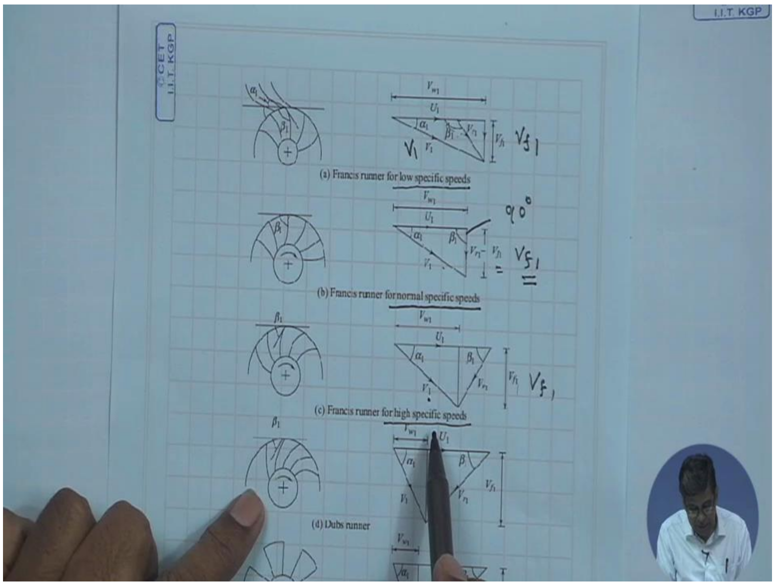

So now here we see that how the development of axial flow turbine has been evolved here. Of course it is difficult for you to see, okay, here, now let us see from here. Okay. No here you see this is a purely Francis turbine, a radial flow turbine. Here is the blades are like this which is at the inlet, the diagram which we already recognised, that this is the inlet flow velocity or inlet, sorry, inlet absolute velocity. This is the component normal to the tangential direction and that is known as the flow velocity VF1, I think you can see this very well, this is VF1 and that is V1.

And this direction is radial, this is normal to the tangential direction. That means liquid at the inlet, water at the inlet for example has absolute velocity which has substantial velocity component in the tangential direction and also in the radial direction. In a purely radial flow machine which relatively, which works at a relatively higher head as compared to an axial flow machine amongst the reaction turbine. A purely radial flow machine works at a relatively higher head when this specific speed is less.

In that case the flow velocity, that is VF1, the velocity normal to the direction of flow is less, is relatively small. So large part is in the tangential component. However this is basically a radial and tangential flow at the inlet and the inlet velocity is very high. This is Francis runner for a low specific speed, means at, is for low specific speed. That means the head is relatively higher. Now when this specific speed increases, for normal specific speed, from low to normal means there is an increase in specific speed for reduction in the head available.

So therefore as I have told when the head available is reduced, that demands relatively more flow through the runner. So the runner blade is designed in such a way that at the inlet the flow velocity, that means the radial component of velocity which is possible for the mass flow rate at the inlet section is increased while the absolute velocity at the inlet of the fluid at the inlet is reduced. The guide vane angles are same but the plate is designed in such a way and the guide blades area, the guide vane area is adjusted in such a way that and inlet, the absolute velocity is reduced as compared to that for low specific speed case.

That means relatively higher head and at the same time if VF1, this VF, this is also VF1 is more than the earlier one. That means as this specific speed increases, we see there is an increase in the flow velocity and a reduction in the fluid velocity of the water at inlet. Similarly you see this is Francis runner for high specific speed. That means from normal specific speed to high specific speed.

So from normal specific speed to high specific speed, that is when the head is still lower, that means there is an increase in specific speed, the turbine blade or the runner blade is made such a way, this angle beta 1, here you see the tangential direction, if we define this angle, this was obtuse. Now here this has become 90 degree, that means this is the velocity of flow and which is coinciding with the relative velocity. That means not only it increases the velocity of flow at the same time the blade at the outlet is in the radial direction, that means radial at the outlet so that the relative velocity and the flow velocity is coinciding with each other.

That means this value beta 1 is reduced to 90 degree, this is 90 degree, this is another aspect. Now when we still increase the specific speed or reduce the head, it should admit more fluid and in that case this is curved in this way so that we get an acute angle for this beta 1. And this becomes the velocity triangle where the absolute velocity of water at inlet is still reduced. And this velocity VF1, flow velocity is further increased. That means what we see up to this is that as we go on increasing the specific speed or reducing the fluid head at the inlet, then the flow velocity is gradually increasing and the absolute velocity of water at inlet is gradually decreasing.

This is done to accommodate more mass flow rate. But up to this, the flow is almost in the radial direction. So it is a purely radial flow turbine, it follows almost the same geometry of Francis turbine. But when the specific speed is much larger, that means the head is really reduced, then what is done, we arrive at a turbine known as Dubb’s runner. This is known as Dubb’s runner.

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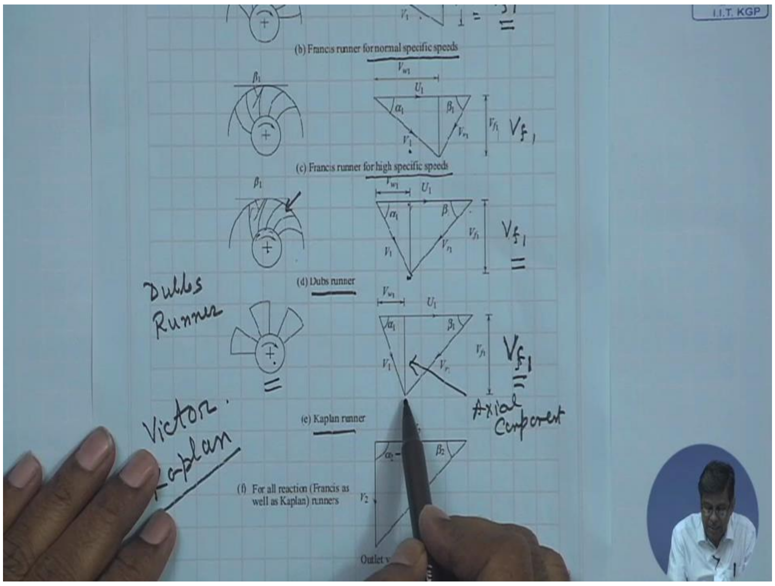

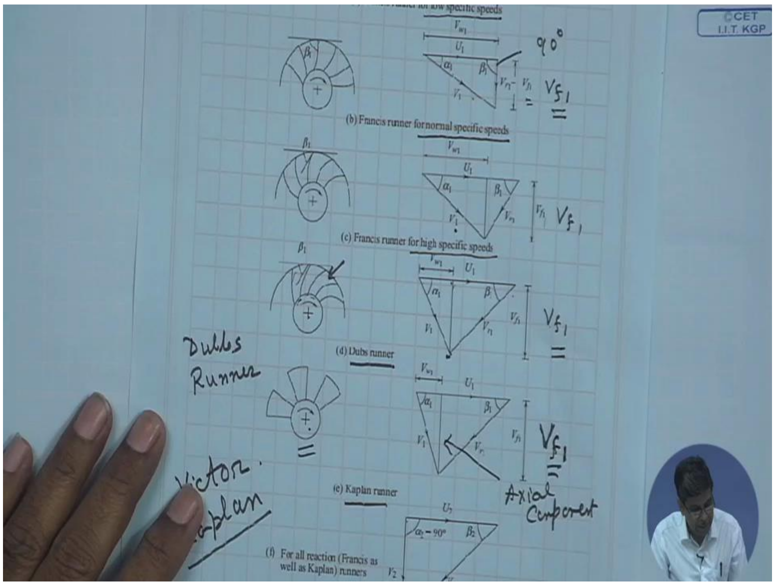

What is done, this is a mixed flow turbine. Here is the entry is radial, radial and tangential, here you see, the entry is, here the flow velocity, that is the radial component of velocity that is perpendicular to the tangential direction is much higher compared to all earlier 3 situations. And at the same time the absolute velocity at the inlet is reduced but the difference is that inlet flow over geometry is same. That means it is mostly the radial and the tangential but the tangential component is less but the radial component or the flow velocity is high.

But while flowing through the blades, it changes its direction, it becomes more in the axial direction and when it comes out of the runner here, the blades are made such twisted so that direction changes and at the outlet it becomes axial. That means if you think in this way I cannot show you a figure, you probably can download a figure from net, I do not know whether you can get it or not. That this is a turbine runner, in a Dubb’s when it comes like that and the blade itself is twisted like that, when it goes out, it is purely in the axial direction. If the runner is in the horizontal plane in the vertical shaft, it goes in the axial direction and this is a typical Dubb’s runner.

And when the flow rate, the specific speed is still higher, that means it has used high-value specific speed where the head is substantially low, we go for a purely axial flow turbine which is known as Kaplan turbine after the name of Austrian engineer Victor Kaplan. So this is a purely axial flow turbine. Here the inlet and outlet, both are axial. Inlet and outlet, both are axial, the blades are made in such a way that inlet and outlet, the blades look like the propeller of machine, and less number of blades are there.

That means the flow, that if you think in this fashion that if this be the turbine, its flow is like this. That means it is in the axial direction, that means the guide vane at the inlet already turns the flow to the axial direction. So the turning takes place through the guide vane. And the entire flow through the runner is in the axial direction, both that inlet and outlet. And these types of machine have less number of blades and provide a very high value of the cross-sectional area in the horizontal plane which sometimes we tell as frontal area.

That is normal area to the direction of flow and can accommodate huge amount of flow rate and can work at a substantially lower head for a very high specific speed. And this turbine was developed much by this Austrian engineer Victor Kaplan and is named as Kaplan turbine. So you seen the Kaplan turbine, this is VF1, the flow velocity which is very high. But a difference between this with the other one, the flow velocity here which is perpendicular to the tangential direction at the inlet is radial flow, that means flow in the radial direction.

Because at the inlet it is tangential radial. But at the outlet, it is radial but it may be axial in case of Dubb's runner. But in case of Kaplan, this is Dubb's runner, Kaplan runner, the inlet is also axial. So therefore this component which we call as flow velocity, that is the velocity in the direction of flow which is perpendicular to the tangential direction, it is axial. That means this is axial component. So this is axial component, that is the difference.

And here all other cases, these components are the radial component. So flow velocity which is the velocity in the direction of flow and perpendicular to the tangential velocity direction at the inlet is in the axial direction. But at the outlet velocities for all runners are like this. Outlet velocities for all runners are like this. What is the similarity for all runners outlet, that the absolute velocity at the outlet does not have any tangential component, does not have any tangential component, the outlet velocity to keep the kinetic energy outlet at minimum.

Okay. But the difference is that in all runners, except Dubb's and Kaplan, where the outlet is in radial direction, there this velocity, the absolute velocity equals to the flow velocity at the runner which is nothing but radial velocity, radial component. Whereas in case of Dubb's runner, the outlet is axial and in case of Kaplan runner, that is beyond the axial flow machine or axial flow turbine, inlet and outlet, both are in axial direction.

So therefore this velocity, absolute velocity which is equal to the flow velocity in this case for Kaplan and Dubb's, this VF 2 will be axial component, axial component, okay. So therefore we see how the, how the concept of axial flow compressors evolves from that of a purely radial flow runner with the increase of specific speed or with the decrease of head available at the turbine inlet. Okay.

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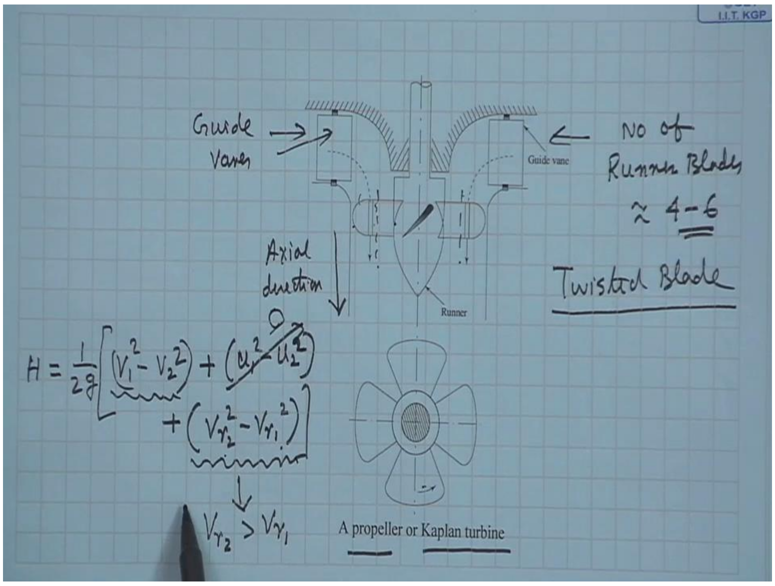

Now we will see an actual, a picture or figure of a Kaplan turbine which is sometimes known as propeller turbine. Here you see that this is the shaft, this has got a vertical, this is the vertical shaft, this is a horizontal plane. This is the runner which looks like the propeller of a ship and this is the runner blade. Okay, we see a frontal view, this is the runner blade, the number of blades, number of, number of runner blades are usually 4 to 6, limited. And it provides a huge normal area of flow.

Not these are the guide blades and this looks like, this propeller, this entire runner looks like a propeller of a ship. It rotates in this direction, in the horizontal plane, the shaft is vertical. Now these are the guide vanes, this is already there in here, guide vanes. So flow comes like this, inlet. So guide vane done the flow right angle to this. This is turned by the guide vane and then flow through the runner blades and purely in the axial direction. This is the axial direction, this is the axial direction.

So therefore what happens, the guide vane turns the flow 90 degree and makes it to flow in the axial direction. Now you see while the guide vane turns the flow, there is a curvature like this, the geometry of this casing and the flow gets some tangential velocity. Some tangential velocity is imparted in the flow, some amount of swallow is imparted in the flow as it reaches the turbine blades. And this swallow in the static part or the stator of the machine can be considered as that of a free vortex flow if we discard the effect of viscosity by the tangential velocity is increasing with a decrease in the radial location from the axis of rotation.

That is the free Vortex rule, that is the relationship of the tangential velocity, its inverse is proportional to the radial distance from the axis of rotation. It can be approximated more closely with a free vortex rotation. But the rotational motion of the blade is solid body rotation which is a force vortex type. That means solid body rotation where the angular, linear velocity is proportional to the radius of rotation, that means the radial location from the axis of rotation.

A combination of this makes a complex flow off a typical Rankine vortex type which is a mix mix of solid body rotation and the free vortex flow. So away from the centre there will be free vortex flow close to the centre of rotation is the force vortex flow and to take care of that these blades are made with it. So in axial flow turbine, the runner blade that twisted blades where the angle of the blade, that is the angle means the angle of the tangent to the profile of the blade with the axial direction is more at the tip and less at the roof.

This is regarding the geometry of the blade and this is a view, if you see from the top, this is the view, 1, 2, 3, 4, as I have told 4 to 6 runner blades, these are 4 blades. Okay, now after this recall one thing, the head that is energy or head, energy per unit weight is 1 by 2G that is imparted to the rotor by the fluid V1 square - V2 square, okay, + U1 square - U2 square + VR, if you recall this at the beginning sessions, we discussed where V1, V2 are the absolute velocity of water or fluid at inlet and outlet.

U1, U2 are the runner blade velocity at inlet and outlet and VR2, we are one of the relative velocity of the fluid with respect to the runner at the outlet. So in case of a purely axial flow machine, U1, U2 component is 0, there is no change because the inlet and the outlet are always at the same radial location. So you can define the velocity at any central plane, that the mean radius of the runner. Now therefore the, this is the change in the dynamic head. So this is the static head. So the change in static head will be obtained only by the change in the relative velocity.

That means if you want, that the reaction machines, it is reaction machine, obviously there will be drop in this static head, that means this static pressure, so we have to change this relative velocity. That means this has to be positive in that case, so VR2 has to be more than VR1. Each means the flow passage, that is the flow area, cross-sectional area normal to the direction of flow, that is normal to the axial direction should be a converging type. So therefore and axial flow machine, maybe purely Impulse machine or maybe a reaction machine. For purely Impulse machine, what we have to do, we have to make the flow passage, that means the flow cross-sectional area uniform so that there is no change in the relative velocity, okay.

So therefore it will be a axial impulse machine. There are machines which are axial flow but impulse. But for axial reaction for axial reaction machines, the axial flow turbines are axial flow reaction machines where the flow passage is a converging type, that means the cross-sectional area perpendicular to the direction of flow, in this case it is the axial direction, the, there is a deduction in the area to increase the velocity to get a drop in the static pressure or static head of the fluid. Okay, in the runner.

So this has to be also kept in mind. So this is axial flow turbine and this is suited for very high head and low, sorry very high specific speed and low head available at the inlet to the turbine. Okay, thank you, today up to this.