Principle of Hydraulic Machines and System Design

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We will continue our discussion on Principle of Hydraulic Machines and System Design. Today, we will discuss about you know the Operational Principle of Kaplan Turbine.

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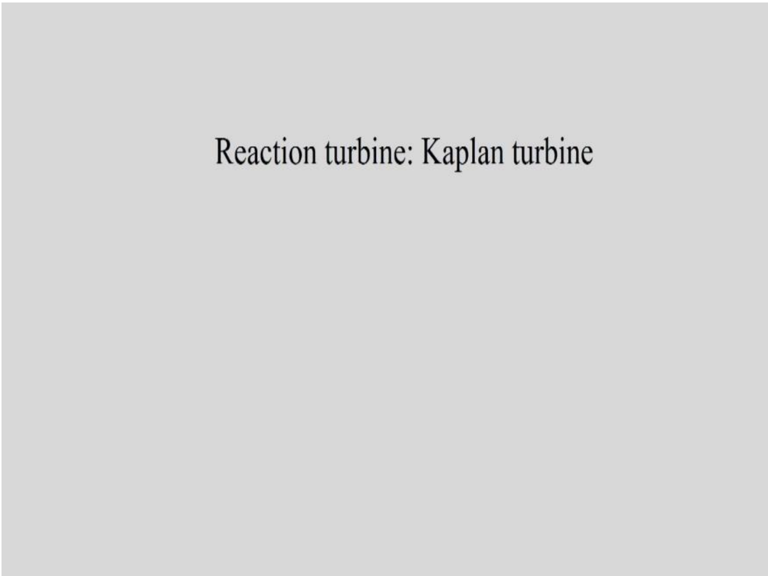

Which is again is a Reaction turbine that is what we have discussed at the beginning, that reaction turbine can be you know divided into 2 categories depending upon the, you know flower at the inlet. So, radial flow runner that is Francis turbine that is, what we have discussed in last class.

So, today we will discuss about Kaplan turbine that is essentially excel flow and runner axial flow turbine. Kaplan turbine is again axial flow turbine, where we have you know adjustable blades, but again we have another kind of axial flow turbine, that is popular turbine where the blades are fixed. So, today we will discuss about the operational principle. So, of let us first you know you know see the schematic of the turbine, then we will discuss about that how fluid is entering to the runner and then what are the different parts of the Kaplan turbine and, and what are the velocity triangles at inlet and outlet.

And of course, we will discuss that why we are going from radial flow runner to the axial flow runner that is from Francis turbine to the Kaplan turbine. So, to do that let us first you know draw the schematic of the turbine. So, I am now drawing the schematic of the Kaplan turbine.

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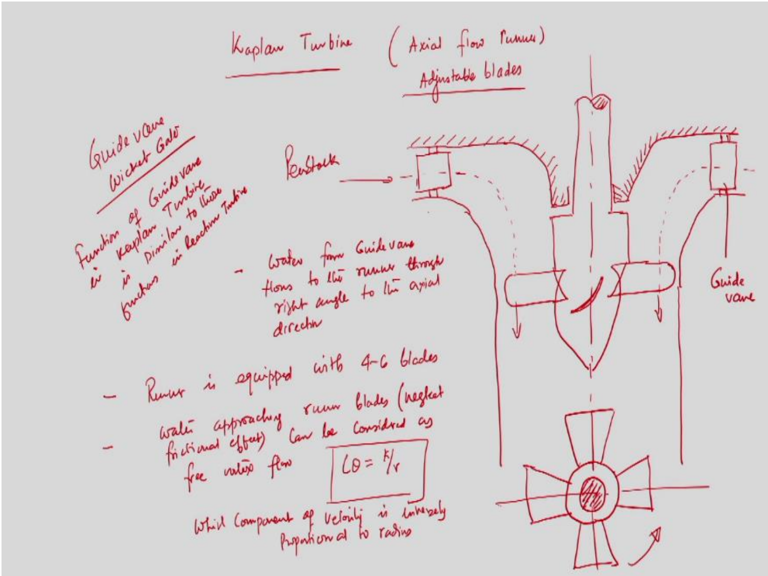

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So, Kaplan turbine as I said you that Kaplan turbine is a reaction turbine, but these having axial flow runner, axial flow turbine runner, where blades are adjustable with adjustable blades, but axial flow turbine again popular turbine is an axial flow turbine, but where the blades are fixed.

So, if we draw the schematic of the Kaplan turbine. So, I will draw the schematic of the Kaplan turbine. So, we will draw the shaft first. So, we have blades we have blades and then. So, let me complete the schematic. So, water is coming and then take a right angle you know turned and it is it goes to the runner, water is coming from the penstock it enters to the. So, water is coming from this is a schematic of the Kaplan turbine. And, if I draw the, you know blade then probably I can draw like this.

So, we have so, we have blade like this normally. So, this is this schematic of the Kaplan turbine. This is you know guide vane, this is guide vane, that is what we have discussed in the last class also that we are having guide vanes or we can gets guide vane guide vane or we call it we can get. So, water is coming from penstock and then it interest to the guide vane. The function of the guide vane is same that is what we have discuss in the last class that they are partial energy conversion takes place and guides the water into the runner.

And, it acts it is acts as a role of governor like think. So, function of the guide vane, function of guide vane in Kaplan turbine is similar to those function of guide vane in Kaplan turbine is similar, to those function in reaction turbine. I mean. So, function of guide vanes and Kaplan turbine is same or similar to those functions in reaction turbine. I mean it it convert partial energy conversion and also it guides the water into the runner also it acts as a governor.

Now, water is coming from penstock and it now goes to the runner. And, while it is going, we can see from the schematic itself, that it take a 90 degree turn, that is very important, that you know when in a Kaplan turbine. So, this is very important water or working fluid. So, we are talking about hydraulic turbine of course, water is a working fluid.

So, water you know from guide vane water from you know guide vane, you know to goes water from guide vane flows to the runner through right angle to the axial direction. So, water enters into the turbine and axial direction then it comes from runner from guide vanes and enters into the runner by taking a right angle turn to the axial direction.

So, then it comes runner. And, normally the runner is equipped with 4 to 6 blades. In a Kaplan turbine runner is equipped with 4 to 6 blades not more than that. And, whenever water is approaching to the runner, we normally ignore the frictional effect and as if it approaches free vertex, I mean free cortex flow. So, when water approaching runner, I mean runner blades, we are neglecting frictional effect.

So, water is very important, when water approaching runner blades normally Kaplan turbines are used for very high specific speed, very high specific speed disturbance are used normally. Because, we have discussed in case of a pumps that axial flow pumps are used for high you know flow rate with low head. Similarly, when speed increases head decreases, that is true for the reaction turbine also, that Kaplan turbines are usually suitable for high specific speed that is speed you know head decreases and it discharges more.

So, this very important that it discharge more at the outlet, where speed is high specific speed is high and in head is less. So, when what is approaching runner blades? If, we neglect the frictional effect, we are neglecting friction effect. So, water approaching runner blades can be consider as as free vertex flow. If it is free vertex flow with if it is free vertex flow then we C theta is equal to k by r that is the wall component the velocity is inversely proportional to the radius inversely proportional to the radius.

So, this very important that even and the runner is rotating in this direction. If, would take a top view, so this like this. So, it is rotating like this. Now, so, shaft is rotating like this. So, water approaching runner blades we are considering no frictional effect and we are assuming that the flow approaches free vortex flow pattern, where wall component of the velocity is proportional to the inversely proportional to the radius, that is what is really important. That wall component the velocity, wall component of velocity is inversely proportional to radius. So, this is one aspect that we are considering free vortex flow pattern without friction.

On the other hand, the blade velocity, we know that blade velocity is equal to pi dn by by 60. So, that is you know proportional to radius. Now, if we go to the next slide. We have seen that, when water approaching from guide vane to the runner. We normally ignore the frictional effect and the flow approaching a free vortex flow pattern, where wall component of velocity is inversely proportional to the radius.

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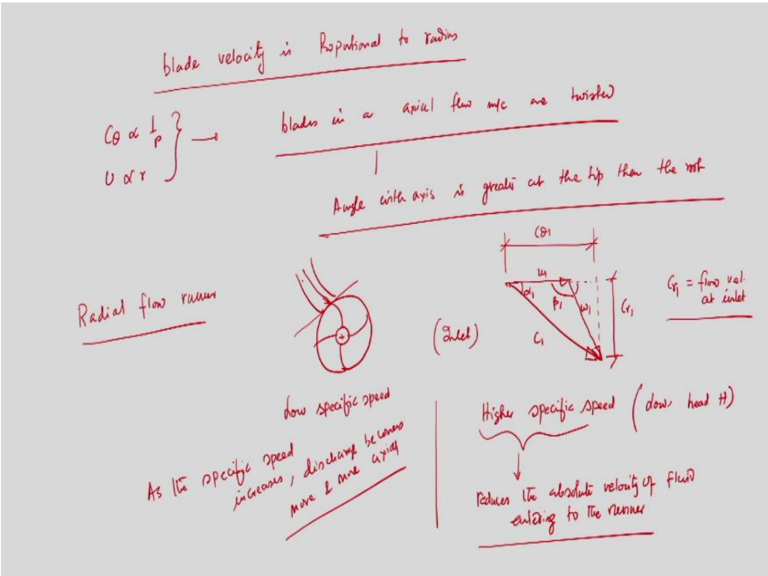

Now, the blade velocity very important blade velocity is proportional to the radius to radius. So, you have seen that thus wall component velocity is inversely proportional to the radius, while the blade velocity with directly proportional to the radius not inversely proportional to the radius. So, there the relationship of wall velocity and blade velocity radius is completely different.

So, now to take this effect into account that this is 2 take care this different relationship to take these relationships. I mean blade velocity is directly proportional to the radius and wall velocity is inversely proportional to radius. So, to take these you know mismatch in the relationship into account normally the blades in axial flow machines are twisted. So, we have seen that C theta is inversely proportional to the r and blade speed is proportional to the r, these 2 different relationships. If you need to take into account, then and that is why blades in an axial flow turbine, axial flow machine rather, axial flow machines are twisted this is very important.

So, blades are twisted why? Because, we have seen that the wall velocity is inversely proportional to the radius and blade velocity is proportional to the radius. So, we have to take these 2 different relationships into account and for that normally blades in axial flow machines are twisted.

So, this is important the angle with axis n is greater at the tip, than the route now whenever they are twisted is important that angle. So, we will have a angle twist. So, we are twisting blades. So, angle with axis is greater at the tip than the route this is important. So, that is why I am discussing that, why another important aspect is blades in axial flow machine are twisted, where angle with axis is normally higher at the tip than the route.

And, if we go back to my previous slide, where we can see that this is a axial flow axial flow runner where fluid from penstock enters to the guide vane compel in the axial direction. Then, when water is flowing or working fluid is water of course, here then water is coming from guide vanes to the runner and then it takes a right angle you know to the axial direction.

But, when it approaches to the runner blade, we are assuming that no frictional effect and the, you know flow approaching the free vortex flow where C theta the wall component velocity is inversely proportional to radius. And, it is rotating and as I said that the Kaplan turbine where it is a axial flow runner axial flow turbine, where we are having adjustable blade is suitable normally for high specific speed and it discharges more and normally for a less head.

So, now this is the operational principle of Kaplan turbine, we will work out one example, but before we go to do. So, let us first discuss about why we are moving from radial flow runner to the axial flow runner. This is very important, that is you know if we discuss that we have seen that the velocity triangles at the inlet and outlet for a radial flow runner, that is for Francis turbine while we have where, when we have solve 1 problem in the last lecture.

And, why we are you know going from radial flow to the axial flow, I mean then, I mean if we change the specific speed, then we need to change the shape of the you know runner. I mean then why I mean of course, the Kaplan turbine is the development the axial flow turbine, while you are going from radial flow runner radial flow runner. And of course, this development is essentially for a change in the specific speed depending upon the depending upon the head available. As I said you that, Kaplan turbine is suitable for high specific speed head is less.

So, turbine installation turbine design and power output from the turbines also depends upon the head available at the net head available at the inlet. So, if we need if we have less head then of course, if we would like to get power output who have to change the shape of the runner. Of course, if we need to change the shape of the runner and also the inlet and outlet velocity triangle will change.

So, the evolution of the, you know change in the shape of the radial flow runner is essentially and you know development of the Kaplan turbine, that is what we now discuss. That how, if we discuss about that radial flow runner at different specific speed, and if you go to high specific speed then what is happening and how we can develop the Kaplan turbine?

So, to do that, we will discuss about radial flow runners for at different speed; so, if I talk about the, you know radial flow runner radial flow runner at different specific speed. So, if you talk about low specific speed say, we have a runner that is what we have discussed and when water is coming. So, water is entering like this.

So, this is the, you know tangential direction. So, if you draw the velocities. So, this is for low specific speed. So, if we draw the inlet velocity triangles, what we will obtain? This is absolute velocity c1, this is blade velocity u1. So, this is this wall component velocity at the inlet $C_{\theta 1}$, this is w1 and this angle is alpha1 this angle is this angle. So, is β_1 and this is the Cr1, that is flow velocity at the inlet. So, this is Cr1 is equal to flow velocity at the inlet right.

So, this is inlet velocity triangle for low specific speed Francis runner, radial flow runner, with low specific speed; so, if we now draw the same velocity triangles, but for a medium specific speed, that is specific speed increase. Let me discuss while specific speed increases, that is very important, then discharge becomes as the specific speed increases, discharge becomes more and more and more axial. This is very important, that specific speed increases, then discharge becomes more and more axial.

We will see soon that us increment in specific speed is essentially a reduction of the absolute velocity of water enter into the runner. So, this specific speed you know so, I am writing that higher specific speed, this is very important higher specific speed, which is equivalent to rather accompanied by you know low head. So, higher specific speed, which is accompanied by low head. So, if we go from low to medium to high specific speed. This essentially reduces the absolute velocity of fluid entering to the runners.

So, when we go for higher specific speed, which is accompanied by low head, that is what we I was discussing that, we need to install turbine, because we need to change the shape of the runner. Essentially to know adjust that, what are the, what is available head? And, based on that head if we would like to obtain maximum amount of power, then you we will of course, we need to change the shape of the runner that is what is the development of the Kaplan turbine.

So, when specific speed increases; that means, head is you know less, because if you we will write the specific speed of a turbine may be in the next lecture, but if we try to recall from the definition of specific speed for a pump $N_s = \frac{N\sqrt{Q}}{H^{\frac{3}{4}}}$. Now, when we go for higher specific speed so; that means, we need to reduce head. So, discharge becomes more and more axial and; that means, specific speed higher specific speed is accompanied by low head, while the high specific speed reduces the absolute velocity of water enter into the runner and that is what is the change of the inlet velocity triangle and we will discuss now.

So, we have seen for lower low specific speed the velocity triangle this is of course, inlet velocity triangle. So, this is inlet velocity triangles, we can see that C1 is very high. And, then we have a flow velocity, but if we now try to draw the runner at medium speed.

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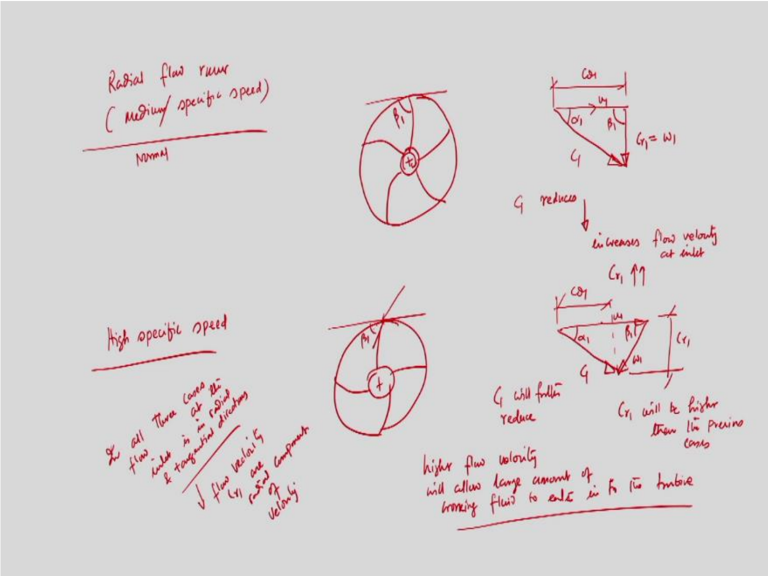

So, radial flow runner, radial flow runner at medium specific speed at medium specific speed, this is very important. The radial flow runner at medium specific speed; that means, if we try to increase the specific speed, then we will eventually see that the flow at the inlet become axial and that is the development of the Kaplan turbine. So, radial flow runner medium specific speed, if we draw. So, I have to draw the schematic again. So, this is the runner like this. And so, this is the tangential direction and this angle is beta 1 that is the blade angle at the inlet. So, if I go to my previous slide. So, this angle is beta 1 that is blade angle at the inlet.

So, now if we draw the so, this is medium specific speed and h will reduce. So, we will if we would like to draw that medium say 6 speed or normal specific speed then, velocity triangle will be like this. We can see from the diagram itself that this is the blade velocity. So, this is Cr1 = w1, this angle is beta 1, this is u 1. And of course, u 1 is equal to this is u 1 and this is $C_{\theta 1}$ and this is C1 this angle is alpha 1.

So, now what we see that C1, you know the as I said that reduces the absolute velocity of fluid enter into the runner. So, here C1 when speed is low C1 is much higher and you know, if we go to here then C1 reduces reduction in C1, this increases because blade speed is specific speed you know increases. So, C1 will reduce, it eventually will increase the flow velocity at the inlet will increases flow velocity at the inlet at inlet that is Cr1 increases.

So; that means, C1 reduces, but the Cr1 increases, now again if we try to draw the schematic of a radial flow runner at high specific speed, high specific speed. So, if we try to draw the runner again, high specific speed then this is what we have discussed in the context of pump. So, this is tangential direction right. So, this is beta 1, this is tangential direction this is beta 1 and if you draw the velocity triangle, we will see that this u 1 will be beta 1 change is beta 1.

So, now this will be you know. So, Cr1, this is w 1, this is beta 1, this is alpha 1, and this is the flow velocity at the inlet this is u 1 and this is $C_{\theta 1}$. So, Cr1 will be higher than the previous cases and C1 will further reduced.

So, what you what you see, that if we go for higher specific speed absolute velocity at the inlet to the runner reduced. And, it eventually increases the flow velocity at the inlet. Since flow velocity at the inlet increase discharge will be high that is very important, that you know it will be so, it will allow large it will allow large amount of fluid to enter into that runner.

So, because of the higher flow velocity so, since flow velocity is increases. So, higher flow velocity higher flow velocity that is obtained with increasing the specific speed will allow a large amount of large amount of working fluid to enter to enter into the turbine. This is important, but if we increase a specific speed, which is accompanied by lower head.

Then, we have seen from the velocity triangle itself that that angle itself that you know the C 1, that absolute velocity of water entering to the turbine will be will reduce. It will eventually increase the flow velocity at the inlet since flow velocity increase, it will allow large amount of working fluid to enter into the turbine.

And, another important aspect that is what I am going to discuss here that. So, if we increase specific speed. So, the flow velocity at the inlet I mean if we say that the flow velocity at the inlet is having 2 components. One is the radial direction, another is in the tangential direction, this is important because we need to know. So, flow velocity at the inlet.

So, if I keep on increasing specific speed, that is what you have seen that you know the flow velocity at the increases, which eventually allow large amount of working fluid to enter into the turbine. And, as I said you that if we increase speed, then it discharges more and more in the axial direction.

Not only that whatever velocity at the inlet flow velocity I mean whenever fluid it is entering to the turbine. So, water when fluid is entering to the turbine that, that a flow at inlet to the runners. So, this very important point to note that, in all 3 cases; so, we have discussed about radial flow runner, but 3 different cases low specific speed medium specific speed or is normal specific speed medium or normal specific speed.

Then high specific speed in all 3 cases we have seen that, that the absolute velocity of water enters into the turbine decreases. It eventually increases the flow velocity allow large amount of fluid to be enter into the, allow large amount of fluid to enter into the turbine.

And, important point to note that in all 3 cases the inlet velocity flow at the runner is having 2 components; one is in the tangential direction, because you can decompose into 2 components, one is the radial direction and another is the tangential direction; that means, the flow velocity C r 1 whatever we are obtaining for all 3 cases are highly radial. So; that means, from here I write that for in all 3 cases flow velocity at the inlet flow velocity at the inlet all 3 cases flow velocity at the inlet is in radial and is in radial and tangential direction. This is very important the flow velocity of the inlet is you know for all 3 cases radial flow runner is in the radial and tangential direction.

So, hence the flow velocity hence the flow velocity 3 cases you know flow at the inlet not flow velocity flow at the inlet. In all 3 cases flow at the inlet is is in radial tangential direction. So, flow velocity C r 1 in all 3 cases that is all 3 cases are radial component r radial component of velocity. So, that is what I was discussing that, if we would like to if I increase specific speed which is accompanied by low lower head; that means, it discharges more and more in the axial direction. And, we have seen that in all 3 cases flow at the inlet is having 2 components. If, I decompose you will have 2 components; one is the radial direction another is the axial direction. And therefore, the component of flow velocity the flow velocities here one is essentially the component the in the radial direction, that is radial component of velocity. So, that is why it is sometimes, when as radial flow runner that is flow velocity at the inlet is radial component.

Now, in case of the Kaplan turbine so, if we go for the higher specific speed again. So, if I draw the higher specific speed of course, that is the Kaplan turbine if we go for the highest specific speed that is the Kaplan turbine.

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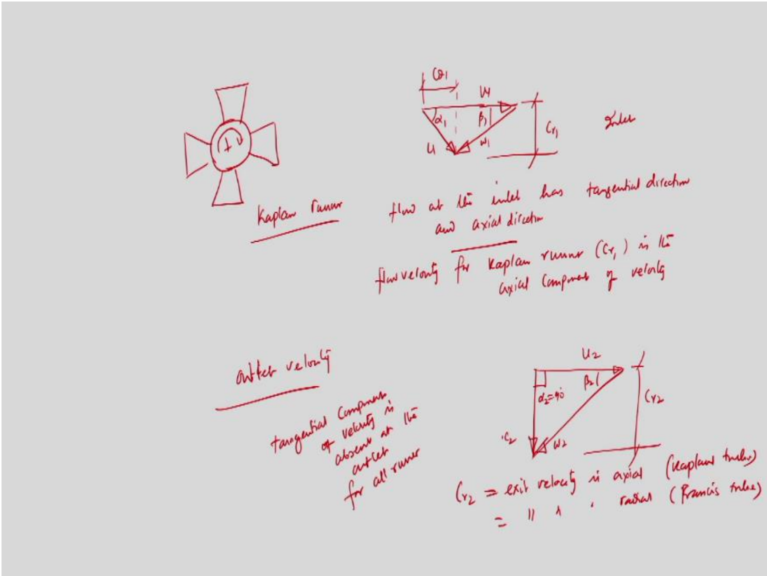

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So, if I draw the runner suppose we have a Kaplan runner. So, this is the Kaplan turbine and if you draw inlet velocity triangle so, if you draw the inlet velocity triangle since the axial flow runner this axial flow runner. So, we will have velocity component like this, this is c1, this is $C_{\theta 1}$, this is w 1, this is u1 and this angle is beta this angle is alpha and this is the flow velocity Cr1.

Now, in case of a Kaplan turbine the axial flow runner. So, we have seen that it is axial. So, the fluid entering flow at the inlet in case of the Kaplan turbine so, this is Kaplan runner. So, fluid is entering in the axial direction that is the parallel to the axis of the shaft, but so, flow at the inlet flow at the inlet has you know 2 components. One is tangential direction and other is tangential direction and axial direction. So, the flow velocity for Kaplan runner that is Cr1 is the axial component of velocity.

So, in case if we would like to increase so, that is what a very important. So, if I up to high specific speed we have seen that, that flow velocity it is having 2 components 1 is tangential and radial direction radial direction. So, Cr1 is of course, represent the radial component of velocity. If I go even further specific speed, then it will be completely I mean in the river's direction. So, now, you can see from the beta itself that here 1 is will be the radial 1 will be the tangential direction other 1 will be in the axial direction.

So, here Cr1 flow velocity represents the axial component of velocity not a radial component of velocity. So, the tangential velocity you almost (Refer Time: 35:40) at the, I mean, hence the flow velocity represents the axial component velocity for you know that is what you obtain, but outlet velocity triangle.

So, this is again inlet velocity triangle. So, outlet velocity triangle outlet velocity triangle if we draw then we will get like this. So, this is c 2, this is u 2, this is so, this is c 2 this angle is alpha 2 is equal to 90 degree, this angle beta 2 and this is w 2 and this one is C r 2. Note, that outlet velocity triangle for all the cases radial flow runner axial flow runner is like this where, you know I mean tangential component of velocity is nil. So, tangential component of velocity is absent velocity is absent at the outlet for all runner.

That means so, exit velocity therefore, C r 2 that is the exit velocity, exit flow velocity is axial no tangential component in all 3 all the runners. So, C r 2 is exit velocity in the axial for Kaplan turbine, while this exit velocity is radial for you know Francis turbine right.

So, what is the outcome of the discussion that if I would like to increase the specific speed, that is accompanied by low head because the head available at the inlet to the runner is very important to obtain the power output from a hydroelectric power plant. So, depending upon the head, if we would like to obtain high power, we need to increase specific speed. So, if we increase specific speed from low to normal to high, we have seen which is accompanied by low head then it discharges more and more in the axial direction.

And, that is what we have seen from the radial flow runner. And, have seen that if we keep on increasing specific speed absolute velocity of water entering to the runner decreases; it eventually increases the flow velocity at the inlet. Now, flow at the inlet is having 2 components one is the radial direction another is in the tangential direction. So, the flow velocity at the inlet for all 3 radial flow runners are essentially is the radial component of velocity, but if we keep on increasing specific again specific speed that is the axial flow runner.

So, it is purely in axial direction. So, we have a from beta 1 itself we can see that you know because specific speed here, the flow velocity the flow at the inlet is having 2 components; one is the tangential direction, another is the axial direction.

But, the flow velocity at the inlet Cr1 is essentially represents is a flow velocity at the inlet Cr1, which represents the axial component velocity not in the I mean not the tangential velocity, but outlet velocity triangles for all cases I mean radial flow runner axial flow runner their tangential velocity is almost nil that the tangential flow velocity tangential component is absent at the outlet.

Hence, the Cr2, which is the absolute velocity, we have nothing to do I mean it all it is only axial it exit velocity at the outlet is axial for the Kaplan turbine. And, this exit velocity you know is radial for the radial flow runner that is a Francis turbine. So, this is what now then we can see that, if you if you would like to know if you would like to increase the specific speed if you have a low head, then of course, we need to change the shape of the Francis turbine runner from shape mean the blade angle we I need to change.

And, eventually we are arriving at that when head is Solo; that means, we have to have higher specific speed then, we essential have to go for the axial flow runner, where the flow velocity at the inlet is essentially in the axial direction, not in the radial direction. And, for all the cases since no tangential component is absent. So, the flow velocity at the exit is axial for axial flow runner, that is Kaplan turbine and it is radial I mean for radial flow runner that is Francis turbine.

So, next to we let to solve on problem on you know Kaplan turbine that is axial flow turbine with adjustable blade.

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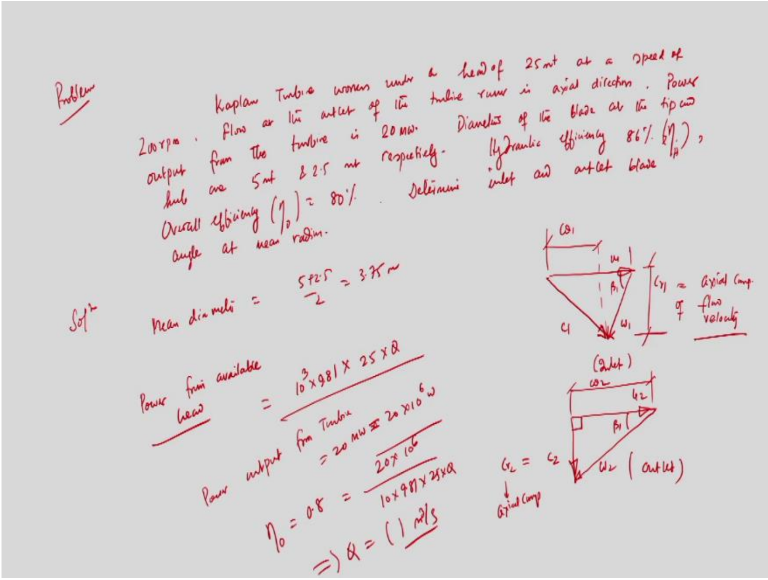

So, next problem is this is very important, that Kaplan turbine a Kaplan turbine works under a head of 25 meter at a speed of 200 rpm. Flow at the outlet of the turbine runner is in the axial direction that is what we are discussing Kaplan turbine power output from the turbine power output from the turbine is 20 megawatts. Diameters at the diameter of the blades, diameters of the blade at the tip and hub are 5 meter and 2.5 meter respectively.

Hydraulic efficiency is given 86 percent that is eta hydraulic overall efficiency eta O that is given 80 percent we have to calculate or determine the inlet and outlet blade angle at mean radius inlet and outlet blade angle at mean radius. So, we have to solve this problem.

So, initially before you go to solve the problem, we have to draw a inlet and outlet velocity triangle. So, if I draw the inlet velocity triangles, we have velocity triangle like this. This is w 1 this is c 1, this is beta 1 and this is the solved compound $C_{\theta 1}$, this is u 1 and this is Cr1. This Cr1 essentially axial component of velocity axial component of flow velocity right, this is at the inlet and outlet we have like this sorry this is c 2 alpha is going to 90 degree. So, C2 = Cr2 again this is axial component this is w 2, this is u 2, and this is $C_{\theta 2}$, and this angle is beta 2. So, this is at the outlet. So, we have drawn the velocity angle inlet outlet, we have to calculate inlet and outlet blade angle at the mean radius.

Mean diameter = (5+2.5)/2 = 3.75 m

Power from available head = 10^3x9.81x25xQ

Power output from turbine = 20MW

So, if I know the flow rate I can calculate this is the power available from the head. Now, power available from the head that we have calculated, but what is the power output from the turbine? So, power output from turbine is equal to 20 megawatt that is that equal to 20 into 10 power 6 watt that is obtained we have we know the efficiency. So, we know the overall efficiency. So, what efficiency, what how much? So, overall efficiency that is 0.8 that equal to 20 into 10 power 6 power output is always less than the power available from the head, because of the frictional losses and windows losses all those thing we have seen divided by 10 into 9.81 into 25 into Q, from there we can calculate what will be the amount of Q meter cube per second this is very important.

So, overall efficiency is power output in the turbine to the power available power from available head. So, if you do like this if I do this calculation you can obtain the flow rate cube meter per second. So, now, we know the Q second obtained is in a rotor speed. So, we have to obtain the mean diameter we have so, rotor mean rotor speed, or runner speed $u_m = \frac{\pi D_m N}{60}$.

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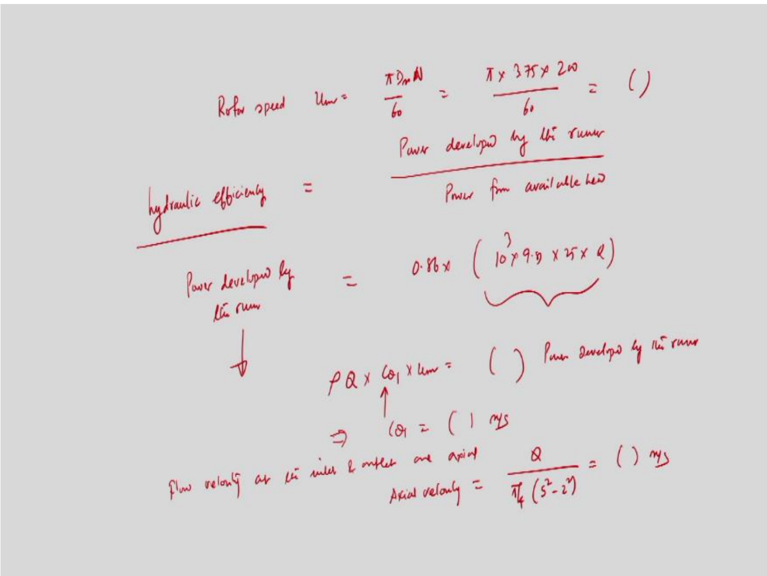

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So, we know Dm that is equal to you know mean diameter 3.75 into 200 rpm divide by 60. So, we will get this thing meter per second.

Now, power developed by the runner this is very important. So, power developed by the runner we know the hydraulic efficiency. So, what is hydraulic efficiency? Hydraulic efficiency we know the overall efficiency is power from the top plant to the power from the available head. Similarly, hydraulic efficiency is power developed by the runner, by the runner to the power from available head.

So, power developed by the runner is how much that we can calculate. So, power develop by the runner can calculate is so, power developed by the runner that we do not know power developed, by the runner that we do not know will be equal to hydraulic efficiency

Hydraulic efficiency = $\frac{power\ developed\ by\ runner}{power\ from\ available\ head}$

So, that is what you obtain. Now, question is what is the power developed by the runner? That will be equal to how much, because power developed by the runner is rho Q into $C_{\theta 1}$ that is wall velocity of the inlet into um. So, if we know the power developed by the runner this expression then if I quit this quantity, I already know that value of Q, I know rho I know u m. So, from there I can calculate $C_{\theta 1}$ will be how much meter per second.

Power developed by runner = $\rho Q C_{\theta 1} u_m$

Now, what will be the axial velocity? So, this is a tangential component of velocity tangential component axial velocity of the inlet that you obtained from, because this is equal to power developed by the runner right. So, from there I can calculate $C_{\theta 1}$, because I know rho I know Q Q I obtained from earlier expression and I have calculated u m the rotor speed they are from there I can calculate $C_{\theta 1}$.

Now, question is very important objective is that flow velocity of the inlet and outlet flow of velocity at the inlet and outlet are I mean axial velocity flow velocity at the inlet and outlet are axial. So, Cr1 rather I can tell that I mean axial velocity I can calculate. So, axial velocity will be $\frac{Q}{\frac{\pi}{4}(5^2 - 2^2)}$ Because, I know Q so, I can obtain axial velocity. So, if I go back to the you know inlet velocity triangle how can I obtain? So, I know $C_{\theta 1}$ if I know the axial velocity at the inlet. So, I can now right then from inlet velocity triangle.

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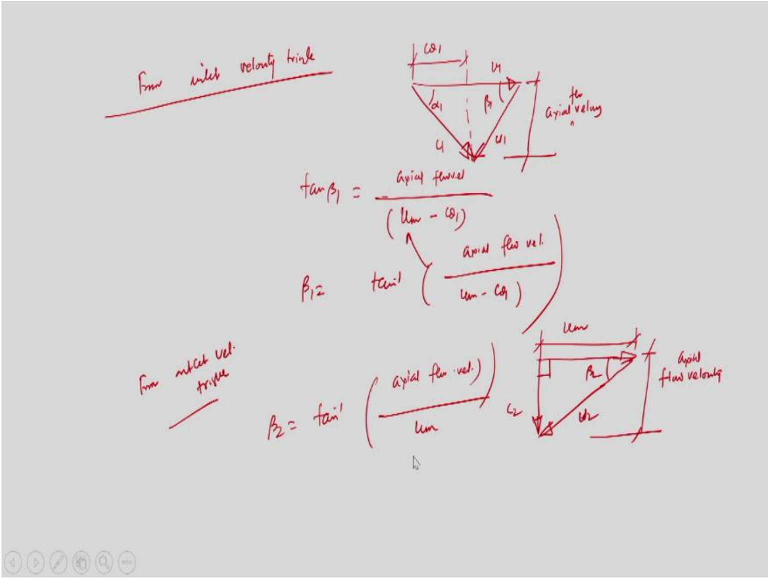

From inlet velocity triangle, what I can obtain inlet velocity was like this again I am drawing the inlet velocity triangle this is w1.

This is let us say axial velocity axial flow velocity this is c1, this angle is alpha 1, this is $C_{\theta 1}$ and total is u 1. So, this is beta 1. So, from inlet velocity triangle what I can obtain $\tan\beta_1 = \frac{axial\ velocity}{u_m - C_{\theta 1}}$ So, we have to calculate mean rotor speed at the mean radius not at the hub and tip, because it will vary from hub to tip from tip to hub. So, we have to calculate u m is very important, because you have to calculate that is already given that we have to calculate inlet and outlet that angle based on the you know at mean radius and the mean.

$$\beta_1 = tan^{-1}\left(\frac{axial\ flow\ velocity}{u_m - C_{\theta 1}}\right)$$

$$\beta_2 = tan^{-1}\left(\frac{axial\ flow\ velocity}{u_m - C_{\theta 2}}\right)$$

So, we have obtained beta 1 and beta 2. So, so if we would like to discuss what we have discussed today. I mean if would like to re capsulate whatever what we have discussed today is that, we have discuss the operational principle of a Kaplan turbine, we have seen that Kaplan turbine is having guide vane, then we have a runner. So, water from penstock enter the guide vane, then guide vane function is almost similar to those you know what is what are the function, we have discussed in case of a reaction turbine, because there is a partial conversion of energy it guides water to the guide you know runner. And, it also access a governor, then water from guide vane to the rounded text are right angle change I mean tuned with the axial direction, then while approaching to the runner the we have assume that velocity is you know flow I mean no friction is present is frictionless.

And, flow velocity approaching to the fibo text flow hire you know c theta I mean wall component of velocity or soil component of velocity inversely proportional to the radius. On the other hand, blade speed that is of course, you know directly proportional to the radius. So, to take this 2 you know contradictory you know duration into account; one is inversely proportional to the radius, other is directly proportional to the radius.

The blades, normally in you know all the axial flow velocity are twisted. And, angle at the, you know hub angle at the tip is relatively higher than the root. And, then we have discussed that why we go for axial flow, why we need to go for axial flow runner? I mean that is you know evolution of change of shape of Francis radial flow runner that is we have discussed that, if we go for higher specific speed that is if we keep on increasing specific speed, which is accompanied by low head that is true.

If we we will discuss that on the specific speed definition. So, when you head reduces; that means, highest specific speed discharges become more and more axial.

That means, we have seen from the inlet from the receipt angle all the velocity triangle is we did I could not draw velocity angles per scale, but still I can tell that the velocity triangles, we have drawn for low speed, normal speed, and high speed redial flow runner, that the absolute velocity of water at the inlet you know that reduces, which is accompanied by a increment of flow velocity at the inlet. And, we have seen that from the schematic that flow at the inlet is having 2 components; one is radial axial direction, one is tangential direction, other is the radial direction. So, the flow velocity at the inlet represents the radial component velocity.

But, again if we go for higher specific speed; that means, that is case of axial flow turbine, that is be with and that will lead to a change in beta. Then, flow at the inlet we have only 2 components; no radial component, only tangential component, and the axial component.

And form the inlet velocity angle we have seen that that the flow velocity at the inlet represents the, you know axial component of velocity, while for all the cases I mean all the runners. If, we have seen from outlet velocity triangles velocity triangles that that the tangential components almost absent and hence the flow velocity at the outlet is axial purely axial in case of the Kaplan turbine, you know Kaplan runner and it is purely radial for the radial flow runner.

Then, we have solved one numerical problem, how to calculate inlet and outlet velocity triangles, inlet and outlet blade angle, based on the mean diameter of the blade. And, we have discussed about 2 different efficiency; one is overall efficiency another one is a hydraulic efficiency from there we have calculated the tangential wall component and then we have solved the problem.

So, with this I stop here today, and I will continue you know, in the next class next our next topic that is the degrees of reaction and then we will discuss about specific speed. And, we will discuss about the (Refer Time: 57:51) in case of a turbine and then we will surely possible to solve a few problems related to this specific speed.

Thank you very much.