Power Plant Engineering
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Lecture – 25
Problem Solving – III

I welcome you all in this course on Power Plant Engineering, today we will solve some of the numericals based on the hydro power.

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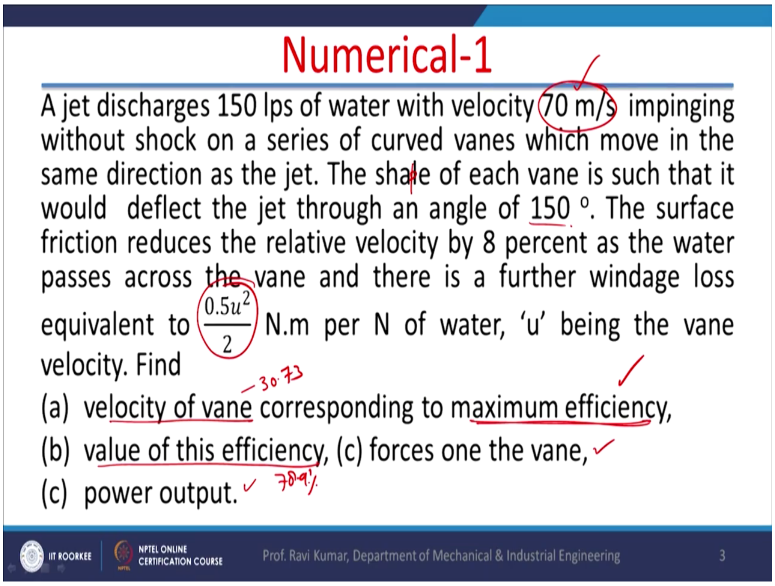

The first numerical I am taking up for the forces on the curve plates it is a jet discharges 150 liters per second of water with velocity of 70 meters per second impinging without shock on a series of curved vanes. So, there are series of curved vanes and the jet is impeding without shock on the series of the curved vanes, these vanes move in the seam direction as a jet. When the vanes are moving in the seam direction, as a jet it means the inlet angles all inlet angles are 0.

The shape it is not shale this is shape of each vane is such that it would deflect the jet through an angle 150 degree. So, when the jet is moving in this direction. So, after is striking the or after sliding over the vane or after it is striking the vane it is deflected at 150 degree 150 degree from the direction of motion.

The surface the friction sorry the surface friction reduces the relative velocity by 8 percent, because the vane surface will offer certainly offer certain resistance and that will reduce the relative velocity by 8 percent. As the water passes across the vane and there is a further windage loss equivalent to 0.5 u square by 2 Newton meter per Newton of water. U being the vane velocity, find velocity of vane corresponding to the maximum efficiency, value of this efficiency I mean the numerical value forces on the vane power output right. So, first of all we will is consider a vane a vane is something like this and jet and the vane are moving in the same direction.

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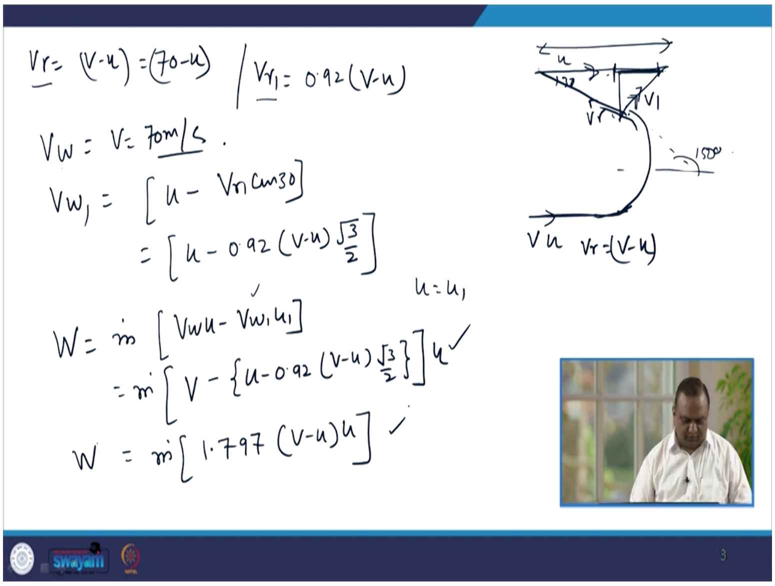

So, the shape of the vane is like this. So, inlet angles are all are 0, this is V u and V r is simply V minus u this is radial velocity. And then jet is giving the vane it is deflected by 150 degree this is 150 and then the vane again is moving in this direction u and then difference of this will give the relative velocity. So, first of all relative velocity at the inlet that V r is V minus u.

Now, V is given here 70 meters per second. So, V minus u is equal to 70 minus u that is the relative velocity at inlet. Definitely the relative velocity at outlet that is V r 1 is going to be because 8 percent losses are there. So, it is going to be 0.92 V minus u ok.

Now, vane velocity V w is equal to V is equal to 70 meters per second and V w 1 vane velocity 1 is equal to u minus V r 1 cos because this angle is going to be 30. And suppose this is u and then this is going to be the V1 this is V r so it is V r cos 30, right or we can say that it is going to be equal to u minus V r 1 we have already calculated 0.92 V minus u under root 3 by 2 this is V w 1.

Now, the work or power output because we are saying work because rate of work we will be calculating because we are using mass flow rate right. It is V w u minus V w 1 u one it is always like that.

So, in that case mass flow rate V w is V minus, because here u is equal to u 1, so u will take out. So, V minus u minus 0.92 V minus u under root 3 by 2 u. If you simplify this expression it is going to be mass flow rate 1.797 V minus u multiplied by u that is the work output rate of work output right. Now, you look at the numerical the deflection is 150 right, velocity 70 meters per second.

So, what we have done? We have first calculated the relative velocity at inlet, after relative velocity at inlet we have calculated relative velocity at outlet, then vane velocity because inlet angle is 0. So, vane velocity is going to be end for the outlet we have calculated vane velocity, because this is relative velocity of the fluid which is going out and it is deflected at 150 degree angle right.

So, this angle is 30 degree and this angle is also going to be 30 degree, this is the vector for peripheral velocity. So, this is the absolute velocity through which the fluid is living the vane, now the horizontal component of this velocity is this one. So, we have taken u this is total u minus V r 1 cos theta.

So, this we will getting this vector right. So, this is how we get we got the vane velocity at the outlet, value of u is equal to value of u 1 right for the vane and then we got the output. Now, after getting the output this is the theoretical one. Now, we have not taking into account the losses these losses.

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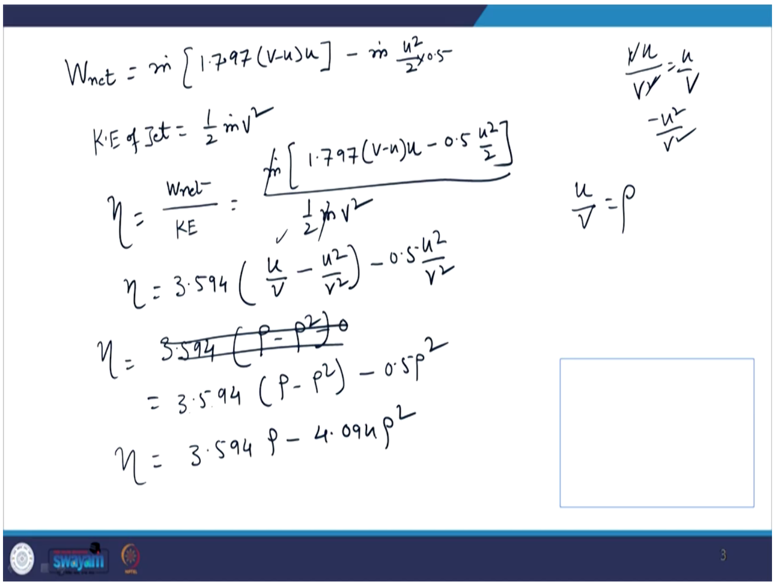

So, if you take it into account these losses, then net output is going to be equal to mass flow rate 1.797 V minus u multiplied by u minus again mass flow rate u square by 2 that is it because it is a 0.5 u square by 2 into 0.5, it is 0.5 u square by 2.

So, mass flow rate so this is the net output we are getting and as you know the incoming energy incoming energy is the kinetic energy of the jet. So, kinetic energy of the jet is half m V square right. So, efficiency is going to be equal to work net divided by kinetic energy.

So, this is the network, so mass flow rate multiplied by 1.797 V minus u multiplied by u minus 0.5 uv square by 2 divided by kinetic energy that is half mv square. Now, this m will be cancelled out and efficiency expression we are going to get 3.594. Now, uv divide by V square will give u by V minus u square by V square minus 0.5 u square by V square.

What we have done? We have simply multiply this 1.797 by 2 and divided this V u divided by V u divided by V square. So, it is u by V and then minus u square by V square has come here similarly minus u square by V square has come here.

Now, u by V if we consider u by V as rho speed ratio, then efficiency is 3.594 rho minus rho square minus this is multiplied sorry 3.594 rho minus rho square minus 0.5 rho square. It can further be simplified as 3.594 rho minus 4.094 rho square.

Because 3.594 plus 0.5, so it lot particularly become 4.094 and that is efficiency. Now, after calculating this efficiency we have to find maximum efficiency, velocity of the vane corresponding to maximum efficiency. If you want to find the maximum efficiency will have to differentiate this term with respect to rho.

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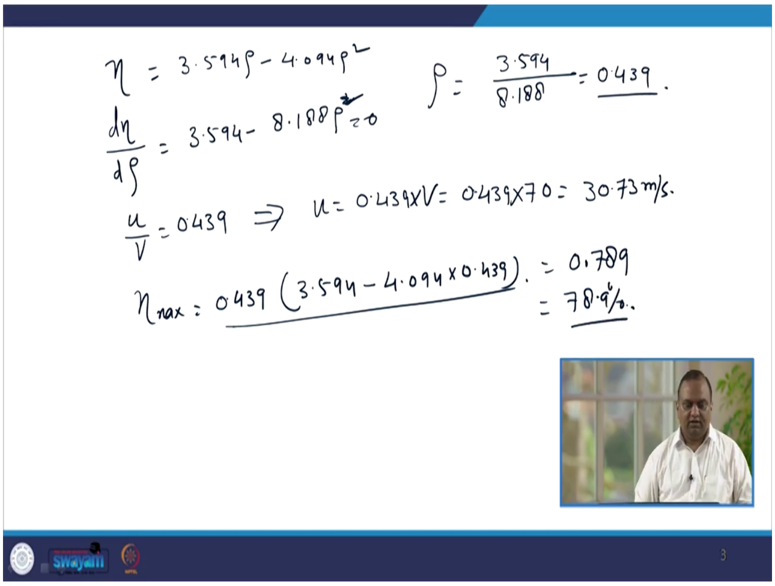

So, first of all we will write efficiency is equal to 3.594 rho minus 4.094rho square. Now, we will differentiate this with respect to the rho. So, d n by d rho is equal to 3.594 minus this multiplied by 2 will become 8.188 yes rho square. And when we are putting this is equal to 0 sorry this differentiate this rho square will not be there only rho.

So, when we are putting this is equal to 0 then we will be getting the valu of rho as 3.594 divided by 8.188 and this is going to be equal to 0.439. Now, u by V is 0.439 therefore, u is equal to 0.439 multiplied by V and V is given here 70 meters per second. So 0.439 into 70 it is going to be equal to 30.73 meters per second that is a peripheral velocity.

Now, once we know the peripheral velocity, we can find the maximum efficiency. It is simply 0.439 that is rho 3.594 minus 4.094 into 0.439. We are use the similar formula you are use the similar formula right and now from here we can get the maximum efficiency and maximum efficiency is 0.789 we multiply it by 100 we will get 78.9 percent that is the maximum efficiency.

So, this one we have already calculated, now the b part is value of the efficiency we have calculated, velocity of vane corresponding to the maximum efficiency we have calculated, velocity of the vane corresponding to the maximum velocity is 30.73, right and value of this efficiency has turned out to be 78.9 percent.

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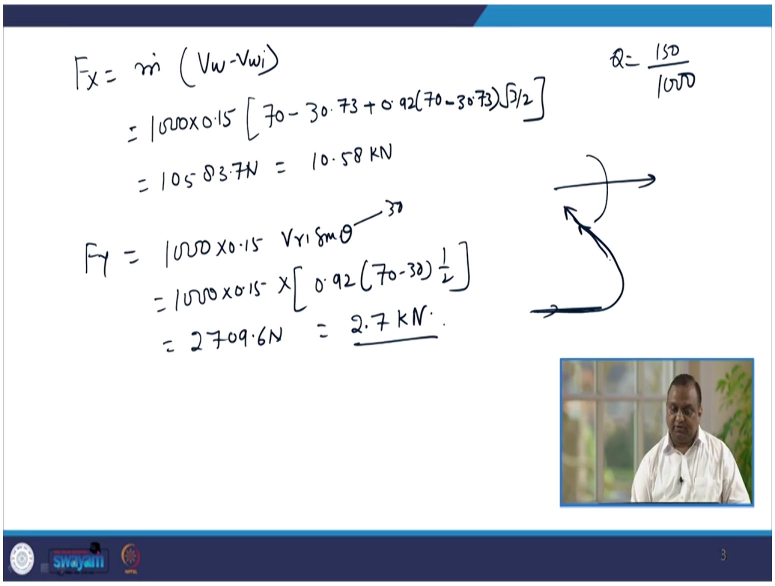

Now, force on the vane; the force of the vane first of all force in was in inter direction it is very simple to calculate. It is mass flow rate multiplied by V w minus V w 1, that is a force in the direction of movement. Now here the discharge is 150 liters per second Q, 150 liters per second means it is 0.15 meter cube per second. If we converted into the cubic meter, so it is going to be 1000.

We are assuming here we are assuming the because density of the water is not given. So, here we are assuming density of the water is 1000 and multiplying it by 0.15 and 0.15 is Q it is 150 lps divided by 1000. V w is 70 minus V w 1 30.73 plus 0.92 70 minus 30.73. I am just putting the values under root 3 by 2 and from this we well be getting ten five 10583.7 Newton or 10.58 kilo Newton that is a force which is exerted on the vane in the direction of the motions right.

Because there is a change in relative velocity, so there is going to be the y component F y right. So, the value of F y is again mass flow rate and V r 1 sin theta, sin theta is here sin theta is 30 because in this vane the situation is like this the movement of the fluid is like this.

So, here because the movement is horizontal in only in the x direction there is no force in y direction. The force exerted in y direction will be through the exit velocity only, but exit movement of the fluid only. Now again we will calculate 1000 into 0.15 into again 0.92 70 minus 30 and sin 30 is half and this will give the force 2709.6 Newton or 2.7 kilo Newton in y direction. Now, power developed the I think last one is the power develop power output. Now, again the power output we will just force multiply force by the peripheral velocity right.

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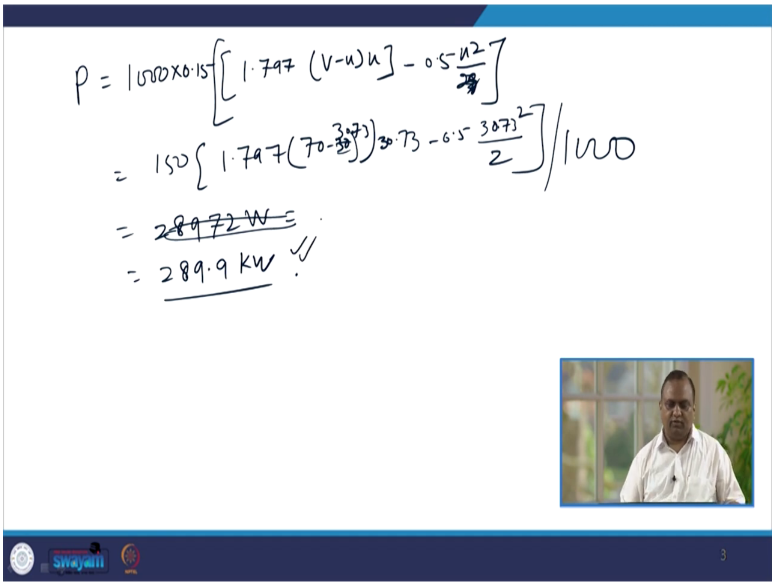

So, in this case power output p is going to be again 1000 into 015 this will give the mass flow rate multiply it by 1.797 V minus u multiplied by u and this is minus 0.5 u square by2 g this formula we have already derived right.

Now, you will simply putting the values that is 150, 1.797, 70 minus 30 70 not 70 minus 730 I think previous 3073 not 30 3073; 30 30.73 minus 0.5 30.73 whole square by now this is not g g will not coming at multiplied by 2.

And this will give the power output as 28 time 872 Watt or sorry 289 will not it will come around 289.9 kilo Watts ok. You just divide by 1000 and this is the final value which we are going to it. So, in this numerical this is going to be 289.9 kilowatts.

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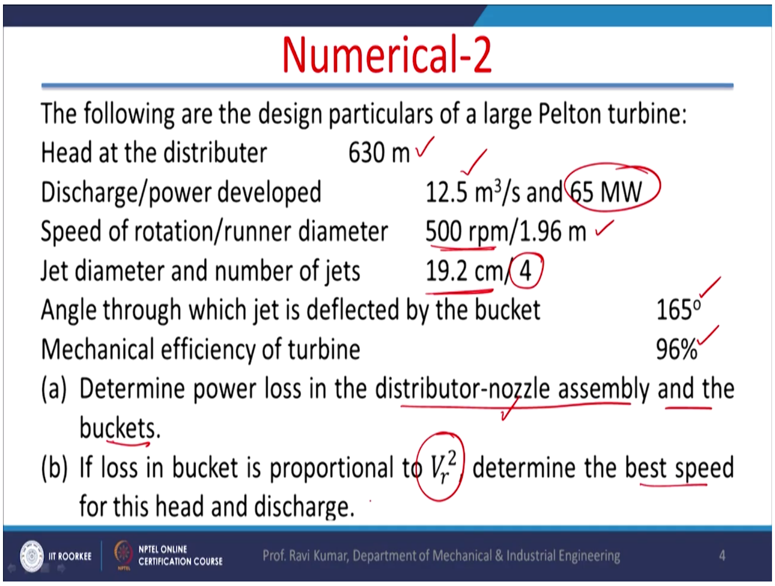

Now, we will take another numerical which is based on the pelton wheel. Now, in a pelton wheel it is a large Pelton turbine. So, these are the design particulars head at the distributor 630 meter. So, we this is the head water head is available and this head is normally generated by making a dam right. Discharge power develop, so discharge is 12.5 meter cube per second and it is developing 65 mega Watt of power.

Speed of rotation is 500 rpm speed of rotation of the wheel, runner diameter is 1.96 meters it is approximately 2 meters. Jet diameter and number of jets, so jet diameter is 19.2 centimeters and there are 4 jets. As I told you in my previous lectures in a pelton wheel it is not necessary it has to be it has to have only a one jet there can be n number of jet in a pelton wheel, so here they are 4.

Angle through which jet is deflected by the bucket is 165 and that is a most desired angle, mechanical efficiency of turbine is 96 percent. Mechanical efficiency is the output and the hydraulic power developed in the turbine, so that is the mechanical efficiency. Output means power available at the prime mover shaft determine power loss in the distributor nozzle power loss in the distributor nozzle assembly and the buckets together.

So, at the entry some power is available and there is an assembly and which distribute fluid in different nozzles. So, because there are bands they are changing directions. So, some losses are bound to be incurred there. So, those losses have to be found out and if loss in bucket is proportional to V r square, determine the best speed for this head and discharge.

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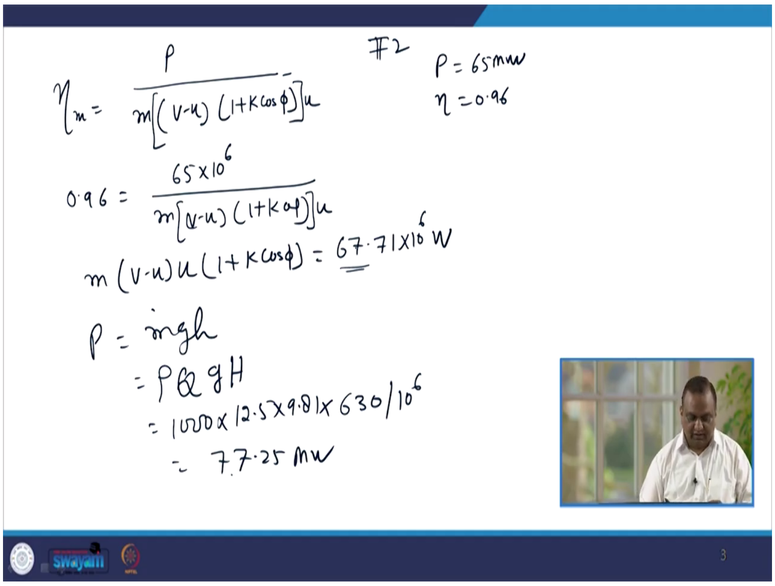

So, for this two numerical numerical number 2, first of all mechanical efficiency, as we know for pelton wheel mechanical efficiency is power output power availability at the shaft and power developed in the vanes and that power is m V minus u 1 plus k cos phi. This is the power which is developed in the vanes.

Now, here mechanical efficiency is 96 percent and power is 65 mega Watt. So, power is 65 mega Watt and mechanical efficiency is 0.96. So, 0.96 is equal to 65 into mega Watt means 10 to power 6 Watts, mass flow rate V minus u 1 plus k cos phi here it will be multiplied by u also it is worth not force it will multiplied by u also.

So, mass flow rate V minus u multiplied by u 1 plus k cos phi is equal to if you simplify this we will be getting 67.71 into 10 to power 6 Watts right. Now, the power supplied now this is the power which is available which is developed in the blades. Now, what was the actual power available? Actual power available was mgh; mgh means rho Q gh and rho Q gh is rho is let us assume 1000 Q is how much; Q is how much? 12.5 meter cube per second 12.5 into 9.81 and h is 630.

So, this power is coming as 77.25 mega Watt. If you divided by 10 to the power 6 then it will come as 77.25 mega Watt. Power develop in the vanes is 67, so this is the difference and this is the loss which is incurred in the distributor right.

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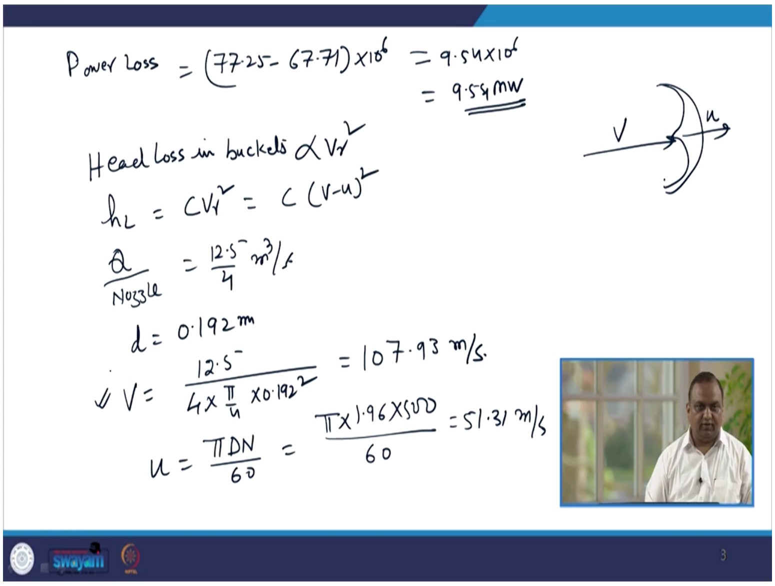

So, power loss in distribution assembly and the buckets is going to be equal to 77.25 minus 67.71 into 10 to the power 6 or it is going to be equal to 9.54 into 10 to power 6 or 9.54 mega Watts. This much power has been lost in the distributor and nozzles.

Now, head loss in the buckets; now head loss in the buckets is proportional to V r square, it is mentioned it is proportional to the Vr square. So, head loss is equal to a constraint Vr square Vr is relative velocity at inlet right and that is going to be C V minus u whole square. Because in the pelton wheel if you remember the shape of the bucket is like this and the jet is striking the middle of the bucket and the bucket is also moving in this direction.

So, if jet is a striking with velocity V and bucket is moving with velocity u then head losses sorry the relative velocity is V minus u right. Now, Q per nozzle is equal to 12.5 by 4 meter cube per second right. Now, this Q is given, then from this Q diameter of the nozzle is also giving 19.2.

So, diameter of the nozzle is given 0.192 meters right. So, the velocity can be calculated as 12.5 by 4 into pi by 4 into 0.192 whole square 190 square and this velocity is 107.93 meters per second, this is velocity at inlet.

Now, peripheral velocity u is equal to pi d n by 60 is equal to pi diameter is what is the diameter 1.96. So, 1.96 n is 500 rpm 500 and divided by 60 and that is going to be equal to 51.31 meters per second. So, now we have the velocity at inlet absolute velocity at inlet and peripheral velocity also.

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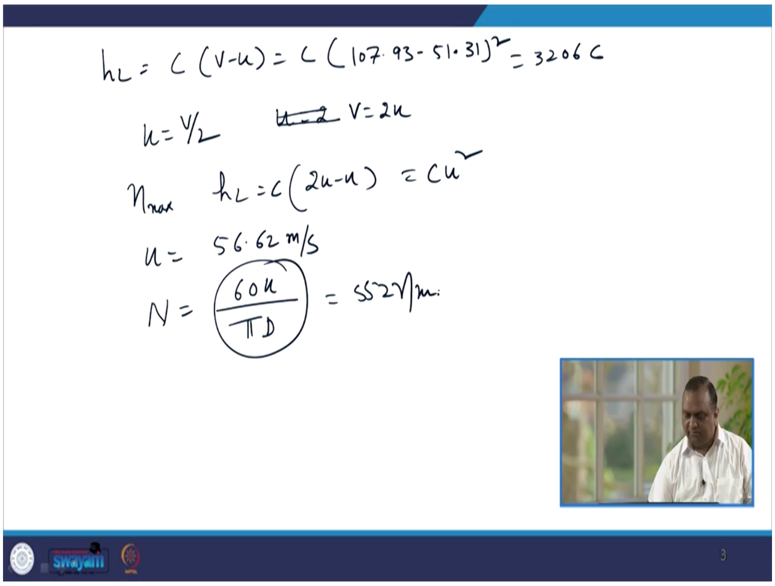

So, head loss; so head loss is equal to a constant C V minus u is equal to constraint C 107.93 minus 51.31 whole square and that is going to be equal to 3206 C that is head loss.

Now, for the maximum efficiency we know that u is equal to V by 2, u is equal to sorry V is equal to 2 u right. So, for the maximum efficiency the head loss is now away from this, suppose you want to have maximum efficiency in suppose if maximum efficiencies there what is going to be the head loss right. Because here in this question it is the loss it is asked determine the best speed for this head and discharge right.

So, head loss for the maximum efficiency is going to be V is 2 u 2 u minus u multiplied by C is equal to C u square. So, for the maximum efficiency u has to be equal to 56.62 meter per second right. Now, once we have the value of u once we have the value of u we can always find the value of N, N is equal to 60 u by pi d and from by putting this value of u pi and d you will get 552 rpm. So, if you run the turbine at 552 rpm and that is going to the best to speed we are the efficiency is giving to the maximum for the given head and discharge.

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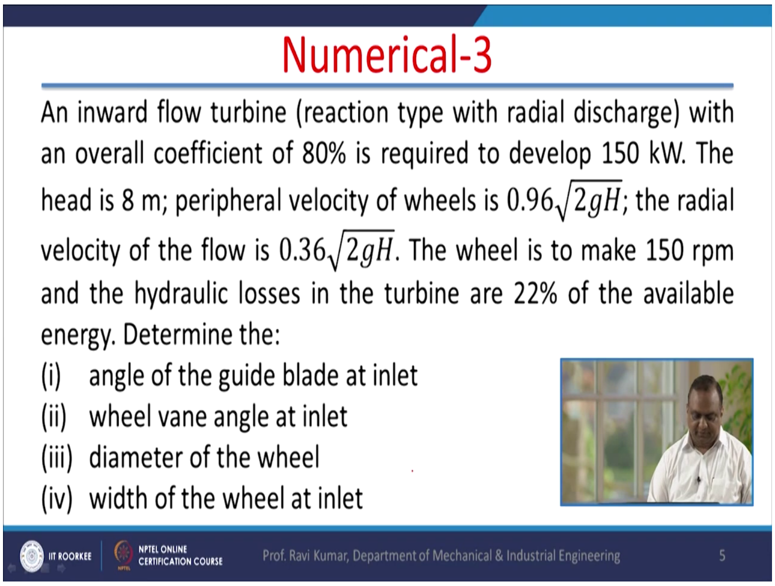

There is also one more numerical on a on a Francis turbine right, an inward flow turbine reaction type with radial discharge. So, it is a Francis turbine with an with an overall efficiency of 80 percent required to develop 150 kilo Watt of power head is 8 meter peripheral velocity of the wheel is 0.96 2 gh that is u.

Radial velocity velocity of flow is 0.36 under root 2 gh wheel is to make 150 rpm and the hydraulic loss in the turbine are 22 percent for of the available energy. Angle of the guide blades at inlet wheel angle wheel angle at inlet diameter of the wheel, width of the wheel at inlet.

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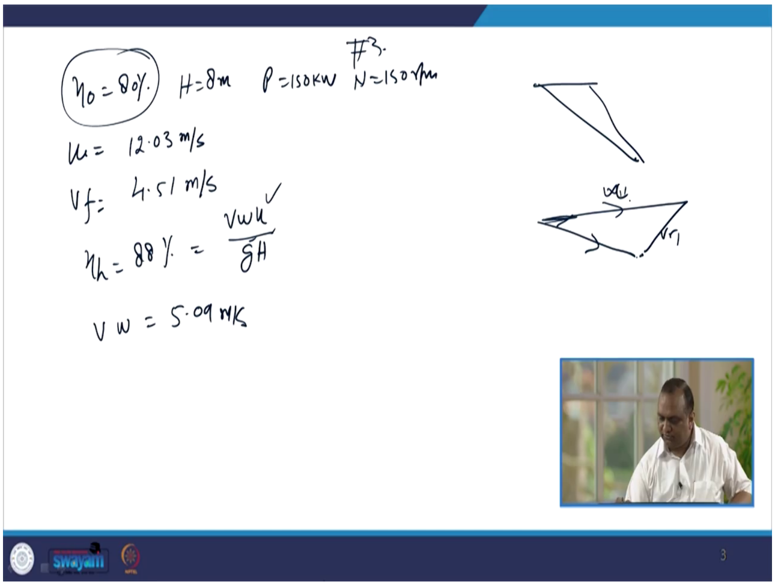

So, for this numerical number 3 overall efficiency is given 80 percent H is given 8 meter power 150 kilo Watt and N is 150 rpm. So, first of all we will calculate u using this formula, because H is known to us. So, when H is known to us that will give the velocity of us 12.03 meters per second, then we will calculate Vf velocity of flow for velocity of flow the formula is given.

So, velocity of flow is again 4.51 meters per second. Now, this overall coefficient which is given here it indicates the overall efficiency. Now, hydraulic losses are 22 percent, so hydraulic efficiency is 88 percent and this is equal to Vw u by g H.

Now, if you put the value of ug and H from here we will get the value of V w as 5.09 meters per second. We have to find angle of the guide blade at inlet, in order to find the angular the guide blade and inlet. So, the inlet triangle if we draw for this it is going to be like this suppose or it can be like this also normally it is like this for Francis turbine, this is V 1 V r sorry this is u V u one sorry this is u [FL] minute.

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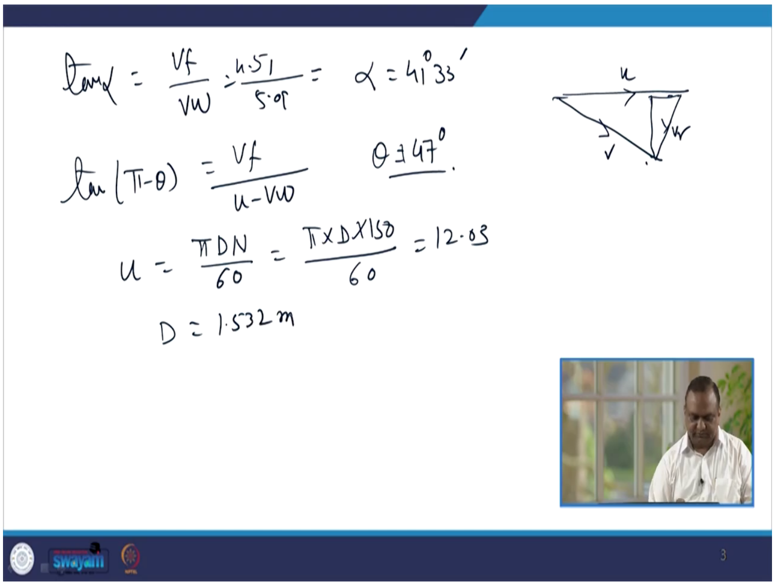

So, inlet triangle for a Francis turbine is like this; this is u this is Vr and this is V right. So, inlet angle is going to be V of tan alpha is going to be equal to Vf by Vw, Vf and Vw we have already calculated it is 4.51 divided by a 5.09 and this will give the value of alpha as 41 degree 33 seconds.

Now, tan pi minus theta tan pi minus theta is going to be the Vf divided by u minus Vw this is u and this is Vw and this will give the theta as 147 degree right. So, both the angles we have calculated wheel vane angle at the inlet angle at the guide diameter of the wheel. So, in order to find the diameter of the wheel we you will use again the same formula pi D N by 60 pi into D N is 150 divided by 60 is equal to 12.03 this will give the diameter as 1.532 meters.

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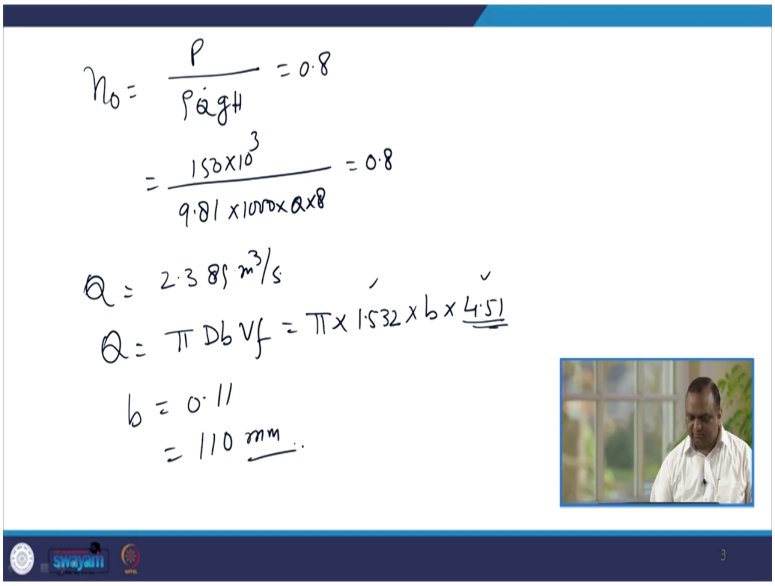

Now, the last one width of the wheel at inlet, so for the width of the wheel at in let we will go by the overall efficiency it is P by power available that is mgh. So, rho Q g H is equal to 0.8 and this is equal to 150 into 10 to the power 3 divided by 9.81 into 1000 into Q into 8 that is going to be equal to 0.8 this will give the value of Q, that is 2.389 meter cube per second. Once we have the value of Q flow rate, then Q is equal to always pi Db Vf area multiplied by velocity of flow.

And that is pi into 1.532 into b into 4.51, because we have already found these this velocity of flow previously and diameter also we have calculated and this will give the value of b as 0.11 or 110 millimeter. So, width of the wheel at inlet is 0.11 meter that is all for today.

Thank you very much.