Power Plant Engineering
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Lecture – 23
Hydro Turbines-I

Hello, I welcome you all in this course on Power Plant Engineering. Today, we will discuss Hydro Turbines, but before that we will continue our discussions on forces on the plates. In previous lecture, we have discussed force on a moving plate.

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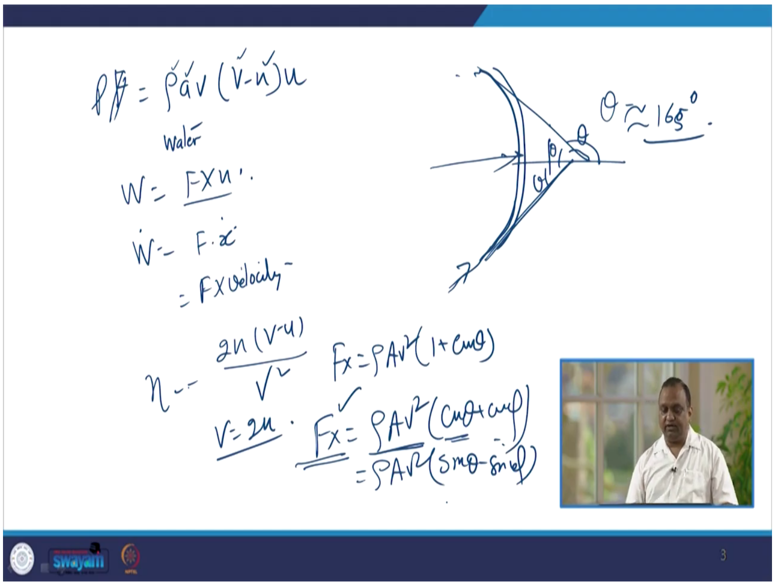

And the force of the moving plate was turn out to be F is equal to rho a v v minus u; u is the velocity of the moving plate, v is the jet velocity, a is the cross section area of the nozzle, and density is the rho is the density of the working fluid and working fluid here is water. From this we calculated the power developed that is work rate of work and we multiplied this force multiplied by u, because if you know that work is equal to force into x distance displacement force into displacement.

And when we want to have rate of work, then rate of displacement is taken into account that is how it comes into force into velocity right. So, here also we will multiply this with velocity and this will be the power developed by the power transmitted to the moving blade.

Then we calculated the efficiency of the moving blade and that was 2 u v minus u by v square. And we also found that v is equal to 2 u, when efficiency is maximum and it is flat plate, if it is 50 percent. Now, if you take the curved vanes because in the turbines their curved vanes, if you want to find the force on the curved vanes, so jet be strike in the middle of the vane or be strike or be slide over the curvature or follow the curvature of the blade.

So, if it is strikes in the middle of the blade, then the force is rho A v square 1 plus cos theta, where theta is the angle of deflection or we may take this also as a theta. If we take this as a theta angle of deflection, then theta is normally equal to 165 degree. If the jets slides over the curvature of the vane in that case the F x is rho A v square cos theta plus cos phi; cos theta is this, and this is cos phi, so theta plus phi. So, this is rho A v square cos theta plus cos this is the value force in the x direction.

Here in this case force will also be there in the y direction and that is going to be equal to rho A v square sin theta minus sin phi this we have already done. Now, if the curved vane is moving, here in this case the curved vane is not moving at all, but in actual turbine if you consider the curve vane which is moving, in that case the force relative velocity will come into the picture right.

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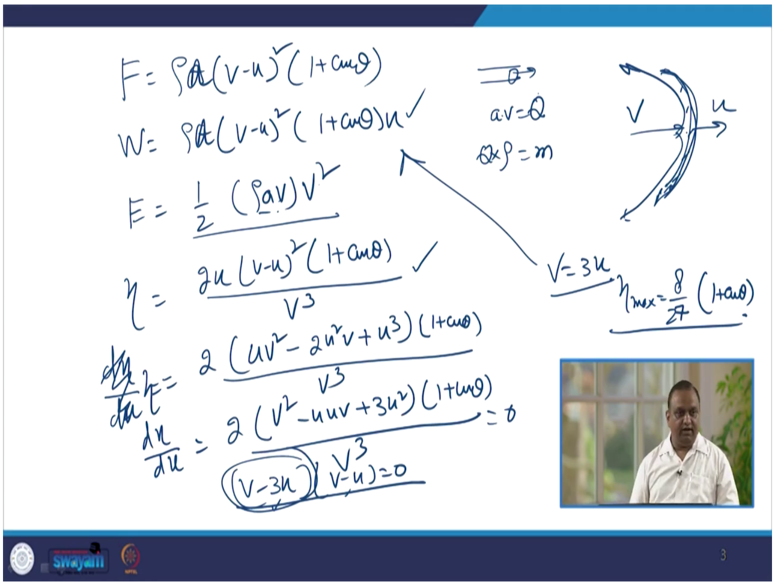

So, force on the blade will be equal to rho A v minus u 1 plus cos theta if the jet is a striking in the middle of the curved plane curved plate this is the curved plate. And jet, jet is a striking in the middle of the curved plate and then it is getting reflected at an angle theta. So, it is rho v minus u square 1 plus cos theta.

Now, in this case work is going to be just multiply this by peripheral velocity, peripheral velocity of the wheel. So, this will give the work transmitted. Now, again energy which is coming to the wheel is half m v square that is rho a v rho v square. Now, this rho a v is, a is the cross section area of the jet, v is the velocity. So, this will be give giving the, a v is the product of a, and v is volumetric flow rate. And this volumetric flow rate when it is multiplied by the density it will give in the mass flow rate. So, it is simply half m v square.

Now, this half m v square is the energy which is coming on the plate and this much of energy is being transmitted. So, if you want to find the efficiency of the whole process, it is going to be 2 u v minus u whole square 1 plus cos theta divided by v cube. This v will multiplied by v square, and it will become v cube. Rho and rho a rho a, and this is a small a right, so this will be cancelled out and this is the expression for the efficiency in this case when the blade is also moving with velocity u, jet is coming with velocity v.

Now, in this case, if you want to find the relation between u and v when the efficiency is maximum or maximum amount of energy is transmitted. In that case, we will have to differentiate this with respect to u as we did earlier also. So, it will give 2 u v square minus 2 u square v plus u cube 1 plus cos theta divided by v cube. Now, this is not d n by d t, this is only efficiency. Now, efficiency divided by d u is going to be equal to 2 v square minus 4 u v plus 3 u square 1 plus cos theta divided by v cube.

Now, if you take this is equal to 0, then you can find that v minus 3 u and v minus u is equal to 0 right, either this equal to 0 or this equal to 0, only there in that case product can be 0. If v is equal to u, no energy will be transmitted because the jet and the plate both are moving with the same velocity. So, there is will be no transmission of energy from the jet to the jet to the plate. But here in this case when v is equal to 3 u, in this case the transmission is going to be the maximum.

And if you put the v is equal to 3 u in this equation, we will get maximum efficiency is equal to 8 by 27 1 plus cos theta. This is the efficiency in the case when jet is a striking in the middle of the curved vane, when the vane itself is moving with certain velocity. Now, in many of the turbines the jet does not strike as the centre of the blade, it is strike it just slides over the curvature of the blade.

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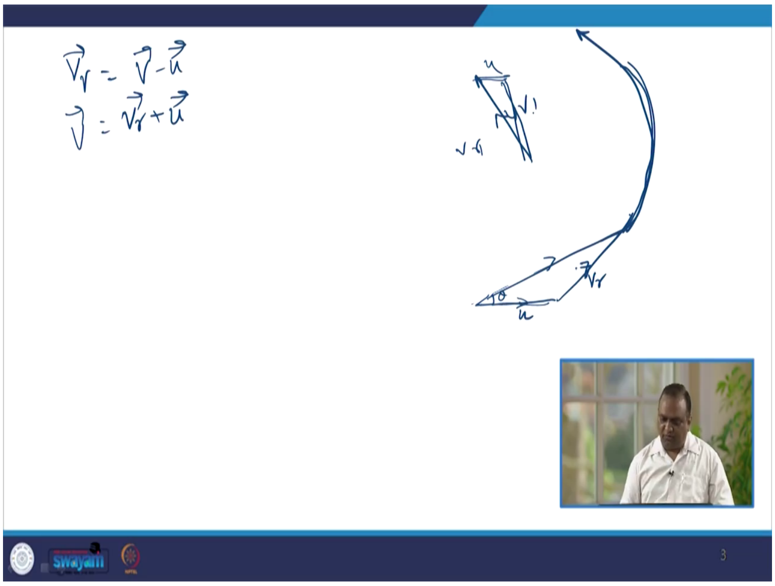

Let me show it like this. So, jet will slide over the surface right. So, this is the velocity through which the fluid should enter the blade. Suppose, jet has velocity v 1, v, and it is strike it is coming towards the blade, and the blade is also moving with the velocity u right. So, the relative velocity is going to be a vector, if we take in a vector, then vector of v minus vector u or vector v is equal to vector v r plus vector u right.

So, this is our vector v r if we add this vector u that is peripheral velocity of the flow of the plate, then this is the velocity v 1 through which the jet should is try to strike the blade. When jet is moving in this direction that is also this is theta. If it is moving with the velocity theta from the peripheral velocity of the plate, then it will not strike the blade it will simply follow the curvature of the blade.

And when the jet will leave in this direction, when the jet will leave with this direction plate is moving in this direction, this is also v r 1 – outside velocity, v r 1, plate is moving in this direction u right, in that case absolute velocity is going to be in this direction that is v 1.

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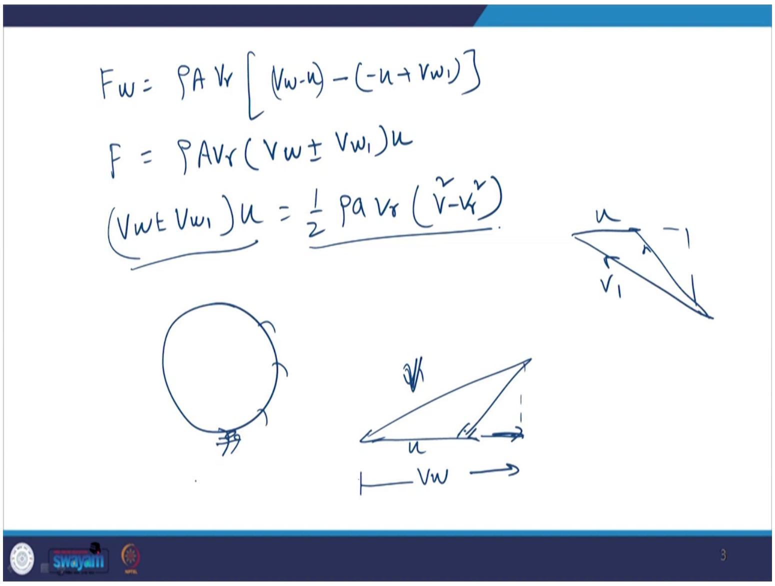

So, they are velocity triangles for the flow of fluid over a curved vane, now if we calculate the forces F w it is going to be rho A, now here we will take into account the relative velocity rho A v r v w minus u this is inlet triangle is going to be like this. So, this is v one this is u and this is this horizontal sorry this is inlet velocity v. So, horizontal component is v w. And this component is v w minus u minus minus u plus v w 1 this is for outlet triangle. When outlet triangle is like this. This is v 1, this is u and because they are in opposite direction in similar fashion we have taken the science.

And this will give the force on the plate as rho A v r v w plus v w 1. It may be negative also; this may be negative also and it may be positive also. And we can say that v w plus minus v w 1 into u, this will give the work. And this work can be equal to half m v square rho a v r v minus v square minus v r square change in kinetic energy. So, change in kinetic energy of the fluid is the energy which is imparted to the fluid over a curved vane.

Now, this is the case when we are considering u as constant, it means there is a wheel, on that wheel they are curved vanes. So, u is constant; u is constant, but imagine in a case or this actually happens in many of the turbines that the u also keeps on changing.

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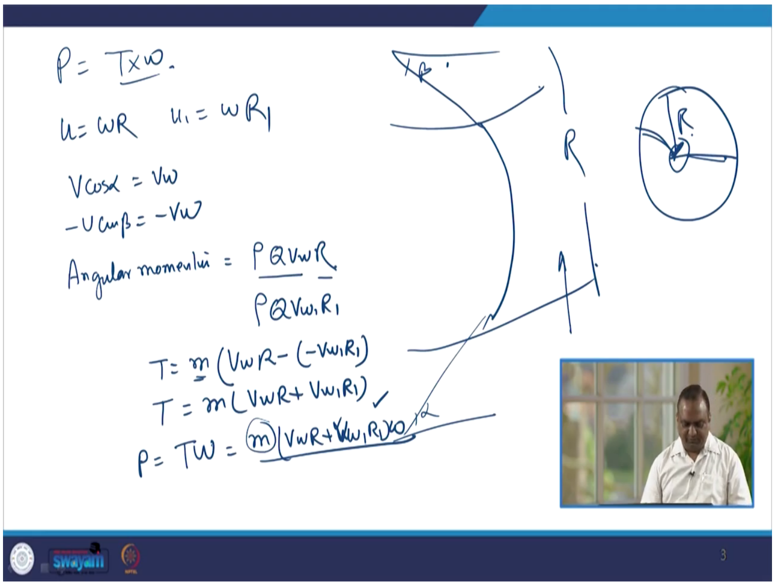

Suppose, there is in a radial flow turbine, u will also keep on changing or this is centre of the radial turbine and it is like this. So, and the fluid is moving in this direction. So, u will also keep on changing. So, we cannot take constantly or we cannot have n number of velocity diagrams that is a tedious process. So, instead of that for the power development we consider torque T into w.

Now, torque u at inlet u is equal to omega R, this is capital R. So, there is a disk this is R capital R, and this is a vane. So, this is capital R or similarly u 1 is equal to omega R 1 this is R 1 omega r this is R 1 and this is capital R from the centre right. And v cos alpha is equal to v w and minus v cos beta is equal to minus v w 1, alpha and beta is the blade inlet and outlet angles, alpha and this is beta they are blade inlet and outlet angles.

So, angular moment angular momentum is equal to rho Q v w R, this is momentum multiplied by r this will give the angular momentum. And similarly at the outlet the angular momentum is going to be rho Q v w 1 R 1. Now, change in the angular momentum, the change in the angular momentum is going to be m v m is the mass flow rate, mass flow rate of the fluid, v w R minus minus v w 1 R 1, and it is going to be equal to m v w R plus v w 1 R 1. Now, this is torque.

In order to provide output p or w it is equal to T omega m v w R plus v w sorry v w 1 R 1 into omega, this will give the output of the rotating wheel. Now, m we can easily calculate, volumetric flow rate multiplied by the density of the fluid. Now, we will discuss the actual hydro turbines, and the simplest turbine is to discuss is the Pelton wheel.

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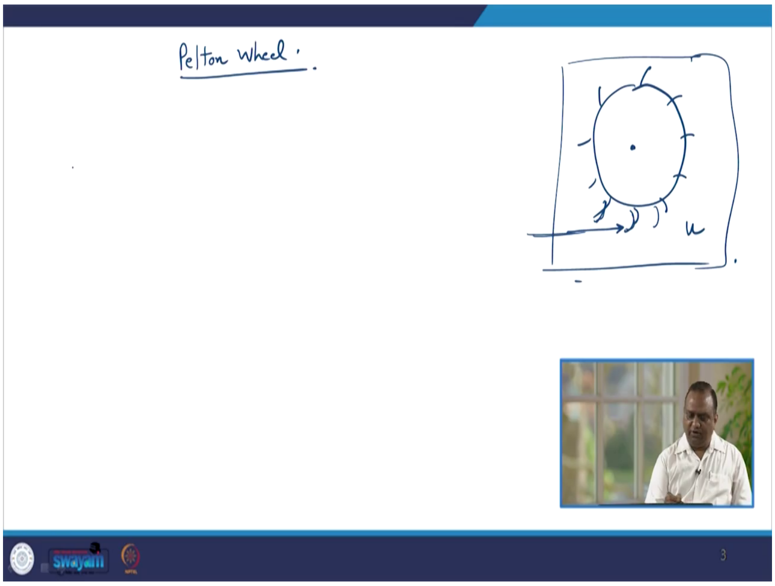

We will start with the impulse turbine and impulse, one of the impulse turbine is Pelton wheel. As it is clear from the name itself it is a wheel, and this wheel has number of buckets; number of buckets right. And water jet strike this bucket, they are curved vanes actually, curved buckets, and water jet strike these buckets which causes torque on this wheel, and this is how the wheel starts rotating right. And it has a certain velocity we can say the velocity of rotation is u, we can have single jet Pelton wheel we can have multi jet Pelton wheel as well.

Pelton wheel type of hydro turbines are used when the head is very high. Let us say 1000 meters or 800 meters, in that case the Pelton wheel is used. And it is a simple the construction is very simple, and the entire wheel is housed in a casing right and jet enters from one side. And we can have multiple jet of multiple jet type of Pelton wheel as well.

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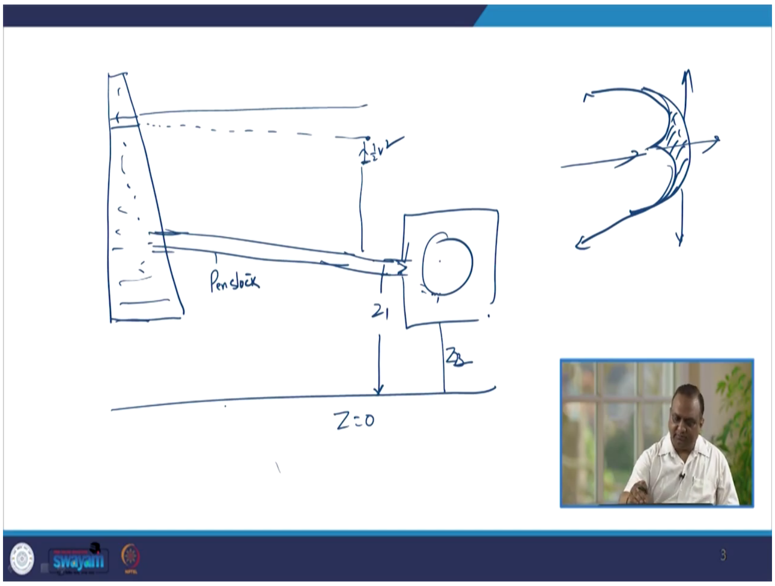

So, in order to develop hydropower, there has to be damned water is stored in a dam. The thickness of the wall of the dam also increases when we go below the water surface because the pressure into, sustained the pressure. Now, in this dam the water is stored, and when the water falls from a height certain height on turbine like Pelton wheel, it imparts kinetic energy to the Pelton wheel and Pelton wheel starts rotating. And with the Pelton wheel, we can connect the generator and that is how the power is generated in hydro power plants.

So, there is a penstock here, penstock through which the water flows and through which after flowing the water it enters the Pelton wheel, it enters the casing. Now, this is penstock, during this course there is a energy loss due to friction. So, total energy some energy is lost due to friction.

So, we have this much of energy. And let us say this is datum where z is equal to 0; this is z 3 – exit of the Pelton wheel; this is z 1 right. Part of this will have kinetic energy half v square or half rho v square we can take if you take one (Refer Time: 17:26) than half rho v square per unit volume. And this is pressure energy because pressure will also be there. All this energy will be converted into kinetic energy here, there is a sphere here which controls the mass flow rate of the fluid and fluid will strike the Pelton wheel, and the Pelton wheel start rotating.

Now, here in this case if you look at the bucket of the Pelton wheel, it is it has a special type of construction. The construction of the Pelton wheel bucket is like. This the reason being when the jet is strike the Pelton wheel bucket, it is this is not a splitter, it is splitted in two parts and moves like this.

Normally, this deflection is approximately 165 to 170 degree, because it is the mass is equally divided in two parts, so vertical component it is cancelled out. So, we do not have any axial loading on this, the entire force is exerted in this direction right.

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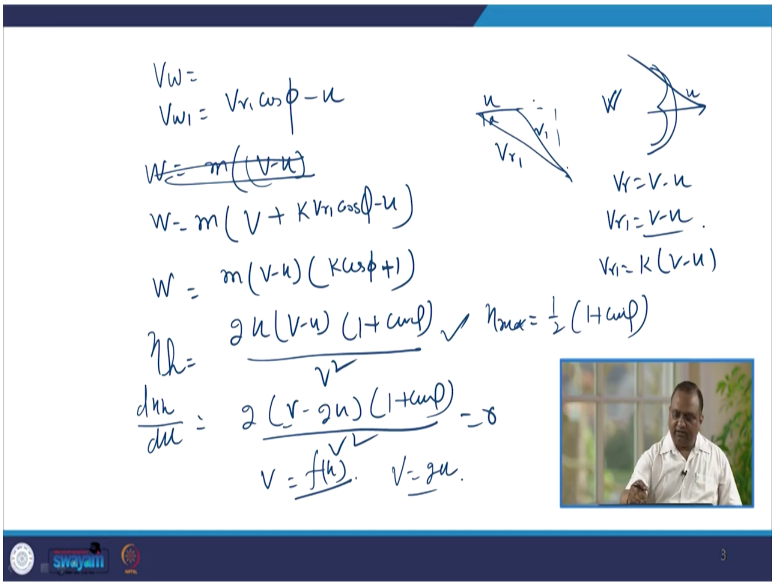

And if we want to draw the velocity diagram of Pelton wheel, so for velocity diagram v w is v 1, because this bucket is moving in this direction let us say u right, and this is v. So, it is v minus u in x direction it is relative velocity is v minus u. So, v r is v minus u right.

And if there are no losses if they are no losses, so we can say that v r 1 also is equal to v minus u right; or if there are losses in that case v r 1 is equal to k v minus u some common constant is there right. So, v w 1 v w 1 is equal to v r 1 cos phi, phi is through which it is the jet is deflected minus u, I am talking about the outlet triangle it is going to be like this is v r 1, v 1 and u and this is phi, so v r 1 cos phi minus u will give us v w 1 right.

So, the work is going to be equal to mass flow rate v minus u, sorry w is equal to mass flow rate v plus k v r 1 cos phi minus u right. From here we will get work as or output as m v minus u k cos phi plus 1. Now, we want to know how much is the hydraulic efficiency of this turbine or how much flowing energy has been transmitted to the Pelton wheel. So, hydraulic efficiency of the Pelton wheel is again 2 u v minus u 1 plus k cos phi by v square, again it is half rho half m v square we have taken into account, the half has gone up.

So, and m and m are considered out mass flow rate is considered out. So, we got this expression. Now, for this if you want to find when the efficiency is the maximum, then we will have to differentiate this with respect to u, and then we will get v is equal to in that case, so it is going to be 2 v minus 2 u 1 plus cos phi by v square is going to be 0. From here we will get v is equal to, so from here we will get the relation between v is a function of u, and efficiency of maximum efficiency of this turbine.

So, v is a function of u, u is equal to 2 times u, 2 times u. So, v is equal to 2 times u. So, maximum efficiency are we are going to get 1 plus cos phi when cos phi is 90, then it is 50 percent right.

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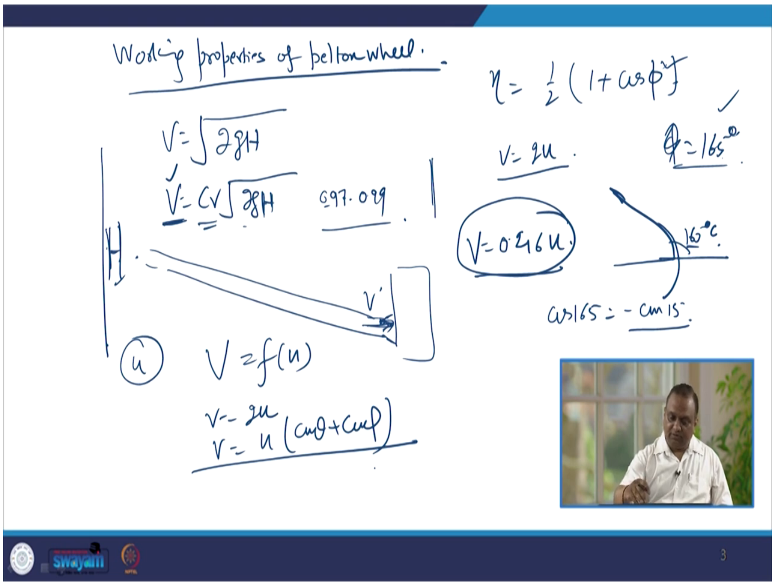

Now, we will take the working properties of Pelton wheel; working properties of Pelton wheel. Now, when the fluid is coming from a certain height from the dam H, so the velocity at the end of the penstock when the fluid is entering the turbine. So, velocity here is going to be ideally it is going to v is equal to under root 2 g H right.

But in actual practice does not happen, because so they are certain losses because one vane contact rise forming here due to this the velocity is the actual velocity is slightly less than this velocity which is expressed by this formula, and it is going to be v is equal to c v under root 2 g H. The value of c v varies, it varies between 0.97 to 0.99.

And now when we design a Pelton wheel, how to initiate the design of the Pelton wheel. So, this is how because this height is known to us, it can always be measured. So, one this was this height can be measured, we can always find the values velocity v at this point. We do not, we can calculate the friction losses also in the penstock when we calculate the frictional loss of the in the penstock will be more close to the actual value which is value of fluid velocity which is coming at the exit of the penstock.

Now, peripheral velocity, what value of u we should take. We have see that there is has always been relation between v and u. We have several number of times we have taken v as a function of u, when it was a flat plate, it was v is equal to 2 u right.

And when it was not a flat, it was a curved vane then v is equal to u cos theta plus cos phi if you remember if the fluid is gliding over the plate surface. So, in Pelton wheel you must have seen we have taken for the maximum efficiency, because we have to choose the value of u which will provide the maximum efficiency or maximum transmission of energy from fluid to the turbine wheel right.

So, in case of this Pelton wheel, we have seen that efficiency is half 1 plus cos phi, half 1 plus cos phi. So, if it is a flat plate we can take v is equal to 2 u always, but in case of Pelton wheel it is half 1 plus cos phi. If you take phi is equal to 165 degree deflection is 165 degree, so then in that case so not phi deflection is 165 degree, so it will be approximately 1 plus cos 15, no deflection is ok, deflection is 165 degree.

So, the jet is striking like this and it is moving in this direction. So, this angle is 165. In that case v is taken as 0.46 u, because here if you put the value of 165 here cos 165 cos 165 is equal to minus cos 15 right. So, in that case we will get approximately v is equal to 0.46 u. And so we it is taken assuming that angle of deflection is 165 degree.

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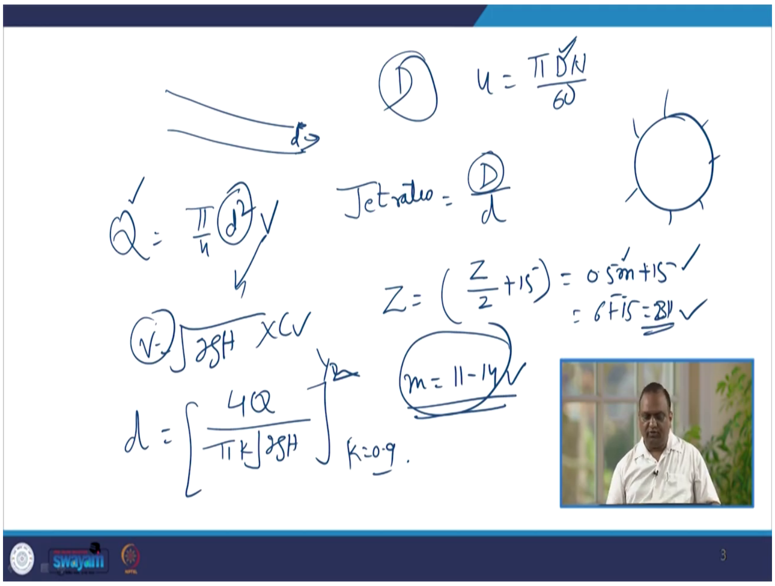

Now, diameter of penstock exit d, this d through which the fluid is entering the casing, as we know the Q is equal to pi by 4 d square into v, v is the velocity at this point. And we have already v have already calculated v is equal to under root 2 g H multiplied by c v. So, v is with us. Q is with us or Q can be measured also or while designing a turbine the value of Q is always given, this much flow turbine rotor has to be design. So, Q is with us. This can easily from here we can find the value of d. So, d is going to be equal to 4 q by pi k under root 2 g H raise to power 2 half, k can be let us say k can be 0.9.

What about D – diameter of the wheel? The diameter of the wheel is going to be we can find easily from u is equal to pi D N by 60, this will give us the diameter of the wheel. Now, the third thing is how many number of; how many number of buckets should be provided on the wheel that is critical 1, 2, 3, 4, 5, 15. So, for this there is a term jet ratio.

Jet ratio is diameter of the wheel divided by the diameter of the jet. And number of buckets in Pelton turbine is going to be equal to z by 2 plus 15 or 0.5 m plus 15 m is the jet ratio right. And this will give you the number of buckets in a Pelton wheel.

So, normally it has been realized for m between 11 to 14, it gives the maximum the Pelton wheel gives the maximum efficiency. So, for the design purpose of the Pelton wheel normally the value of m between 11 to 14 is adopted. Suppose, you take a m is equal to 12, to 12 m is this 6 plus 15 21 buckets have to be there.

So, selection of m depends upon the size of the wheel also, as it is clear it is a function of diameter of the wheel. Higher the diameter of the wheel more is going to be the value of higher is going to be the value of m; lower the diameter of the wheel lower is going to be the value of m. That is all for today. In the next lecture, we will continue with the reaction turbines.

Thank you very much.