Power Plant Engineering

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Lecture - 24
Hydro Turbines - II

Hello, I welcome you all in this course on Power Plant Engineering. Today we will continue our discussions on Hydro Turbines.

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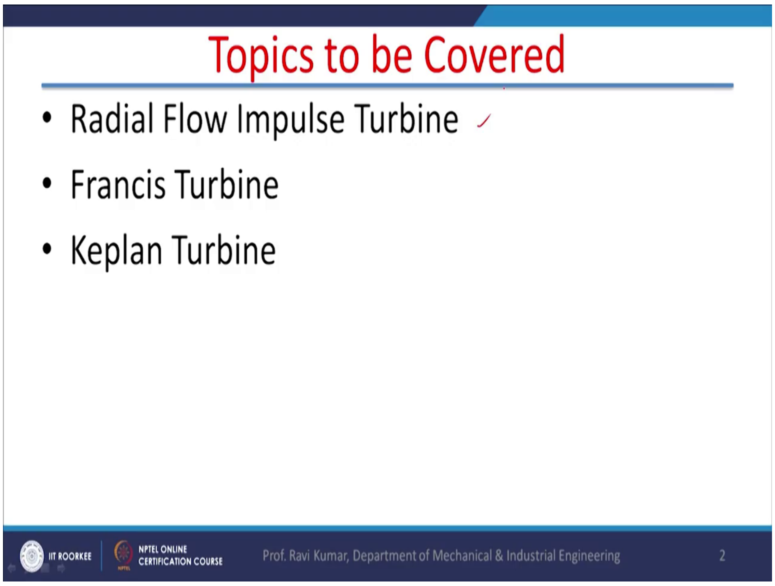

So, topics to be covered today are the Radial flow impulse turbine, Francis turbine and Keplan turbine. I will start with the radial flow of radial flow impulse turbine, radial flow turbines.

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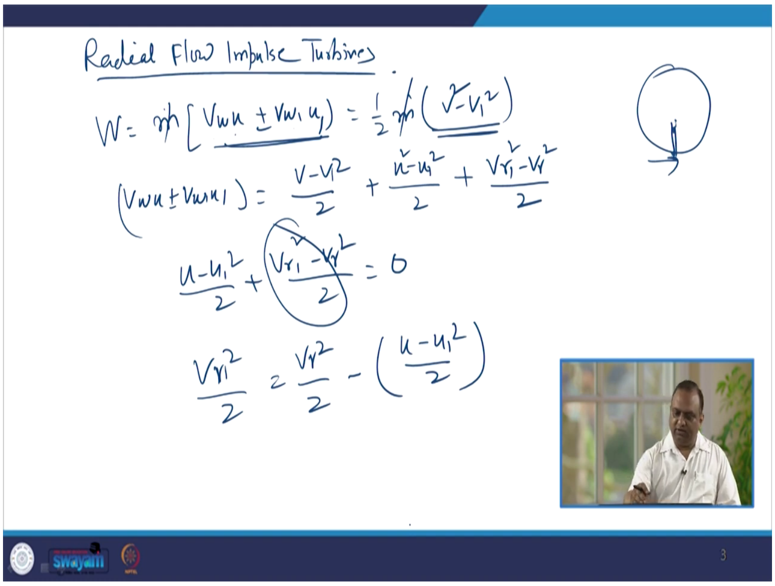

Radial flow means the, u keeps on changing right and u means the peripheral velocity of the wheel, it will keep on changing, as we move from inside to outside or outside to inside. Now the work output I have already explained it is mass low rate multiplied by Vwu plus Vw 1 u 1 it can be negative also so, plus minus Vw 1 u 1.

Vw is the wheel component at inlet and this is u 1, wheel component at outlet this is peripheral velocity at inlet this is peripheral velocity at outlet and this is going to be equal to half mass flow rate V minus V 1 square. This is the change in the kinetic energy and this change in the kinetic energy is in the is has gone to the wheel for power generation.

So, here we can easily find that Vwu plus Vw 1 u 1 is equal to V square minus V 1 square divided by 2, m will be canceled out that is it. Now Vwu plus minus Vw 1 u 1 is also change in the kinetic energy plus change in the kinetic energy of wheel plus change in the relative velocity right. So, if you compare these 2 equations we can easily find that u minus u 1 square by 2 plus Vr 1 square minus Vr square by 2 is equal to 0.

Now, from here we can find the value of Vr 1 square by 2 is equal to Vr square by 2 minus u minus u 1 square by 2, if these 2 are equal then Vr 1 is equal to Vr this happens when there is no radial flow there is only tangential flow to the disk of the blades.

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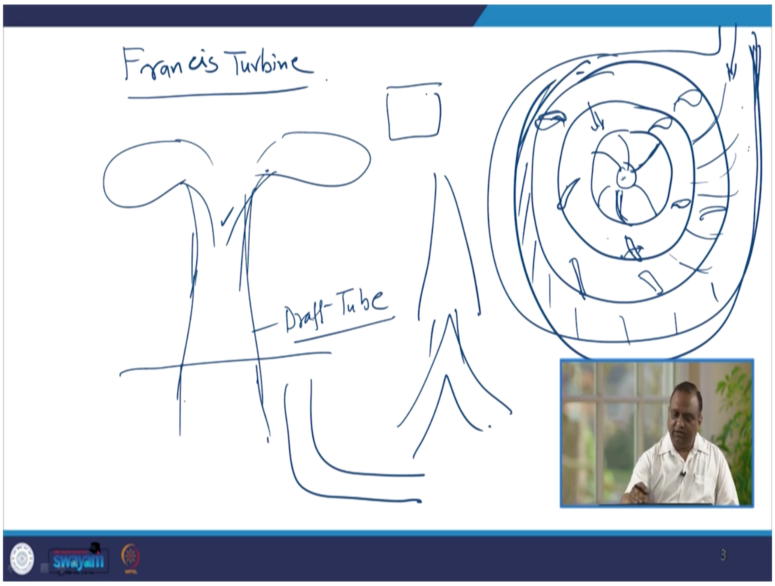

Now we will switch to the some of the reaction turbines and Francis turbine is the most popular turbine in this case. So, let us first understand the Francis turbine, Francis turbine is a radial flow turbine and in this turbine the fluid enters from the periphery of the base, suppose this is this which rotates with a certain velocity right and it has wheels it has an eye and it is has a vanes. So, fluid will enter from the periphery and will leave actually at the center however in the centrifugal pump the fluid enters from the center and leave from the periphery.

So, here fluid will be entering from the periphery and leave from the it will be leaving from the center. Now we have to ensure that there is no shock entry or the fluid should simply glide over the vanes of the wheel right. So, for this purpose there are certain guide vanes it is surrounded by the guide vanes they are certain guide vanes, the purpose of the guide vanes is to guide the chart of the fluid. So, guide vanes they give direction to the jet of the fluid and they can move over a period.

So, they can they can decide the angle of the inlet also right. So, they are flexible there is a there is a pivoted here and they can move there is a angular movement on these vanes and these vanes can guide the direction of the fluid which is entering the which is striking the or which is gliding over the surface of the blade. Now after this there are stay vanes also, stay vanes are also fixed and they are half in number of the guide vanes. So, if guide vanes are 20, stay vane will be 10, they are fixed right and these guide vanes are they also control the to certain extent the quantity of the fluid which is entering the blades and stay vanes they are fixed and the weight of the casing also comes from the stay vanes right.

Then there is a volute casing, volute casing as in the case of centrifugal compressor there is a volute casing here, but from this side fluid enters and it starts distributing here right. As the quantity of the fluid increases or the volumetric of the fluid flow of the fluid reduces because part of the fluid enters here from here it enters the towards or it moves towards this rotor of the turbine right. So, the cross section area of the volute casing keeps on reducing it keeps on reducing actually this cross section area it keeps on reducing.

So, that constant velocity is maintained right and there is a uniform entry of the fluid from all directions, it is it is very important it is very important for the design of the Francis turbine for a for a good design of Francis turbine then there is uniform velocity of the fluid is maintained throughout the casing right. If we look from a different angle the turbine will look like this is the volute casing and after entering after moving after over the blades it will lead the turbine in radial direction. So, it is going to be like this and below that normally a draft tube is provided this is draft tube, the function of the draft tube we will discuss later on right.

The draft tube is provided to just to increase the output of the turbine or the efficiency of the turbine. So, that we can maintain lower pressure here because here the pressure is the atmospheric pressure I will discuss draft tube in subsequent slides. Draft tube can be of different shapes it can be conical, cylindrical or it can have shape like this, it can be in elbow shape also, it is it is has to be not necessarily a cylindrical intersection or parabolic or elliptical intersection, it can be square also, it can be of square cross section also, but draft tube is almost an integral part of a Francis turbine because without draft tube a lot of energy will go wasted right.

Now, we will switch to the performance of Francis turbine.

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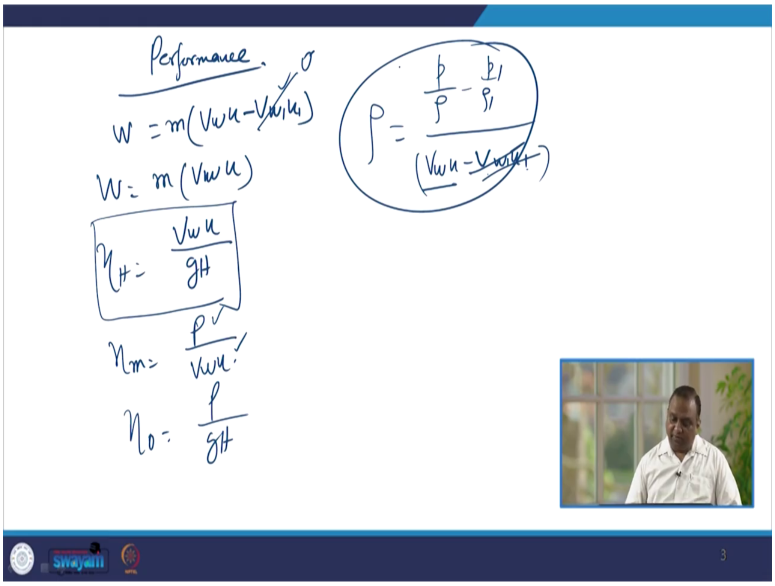

Now we as we have seen that when there is a radial flow of the fluid the work output is mass flow rate Vwu minus V w 1 u 1, but here in Francis turbine outlet is radial when there is radial output there is no wheel component so, this is going to be 0. So, the output of the Francis turbine is mass flow rate Vwu, hydraulic efficiency output divided by the energy available at the entry of the turbine. So, that is Vw u by g H because at the entry of the turbine and will be cancelled out. So, hydraulic efficiency of he this Francis turbine is going to be Vwu divided by g H.

Mechanical efficiency that different type of efficiency, mechanical efficiency this actual power output divided by Vwu this power which is imparted to the impeller is not 100 percent converted into the actual power mechanical power. So, there are certain losses, losses in the bearing, losses due to friction, losses due to in the bearings and actual output divided by the power imparted to the wheel or power develop in the wheel this ratio gives the mechanical efficiency. So, we can say the overall efficiency if you take product of these to then you will get P by g H, actual power we are getting and actual a power which is available.

Now in Francis turbine as I said there is a reaction turbine pressure loss may take place in course of plates also. So, there is always a term which is known as degree of reaction for the design of the turbines, the degree of the reaction is going to be p by rho minus p by rho 1. So, p 1 by rho 1 is equal to Vwu minus Vw 1 by u 1 and this is always 0. So, this is 0. So, Vwu Vw multiplied by u. So, this is going to be the degree of reaction if you want to calculate degree of reaction of a Francis turbine [FL].

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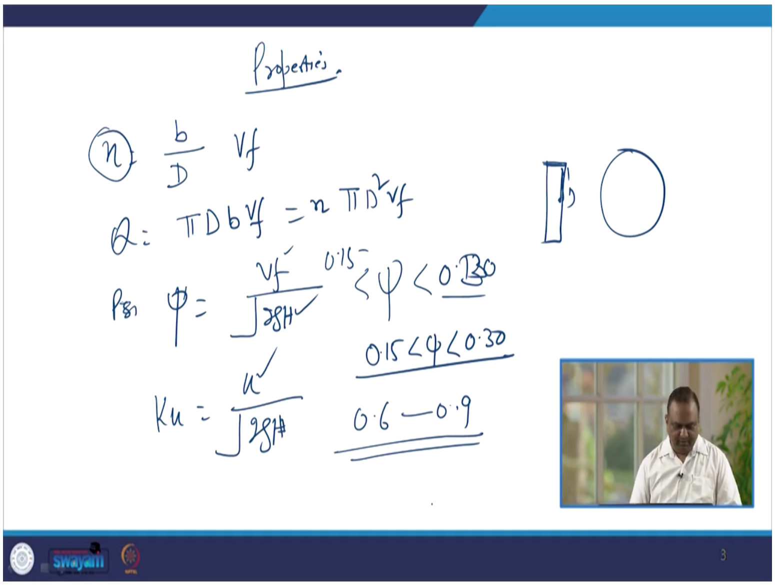

There are certain properties of like Pelton wheel there are certain properties of Francis turbine. The properties is the number n, n is say every wheel I mean the impeller it has certain width right. So, it is width is b and the ratio of b and diameter is known as n and why it is important? It is important when we want to calculate the cross section area of the passage because suppose this is this is a wheel if it is the side view of the wheel right and this is diameter D. So, width diameter D diameter D width and this will give the area which is available for the fluid flow and if you multiply this was velocity of the flow.

We can find the velocity Q. So, Q is equal to pi D b Vf right or n pi D square Vf and velocity of flow we can always take from the velocity triangle right and further there is a term psi it is Vf by under root 2 gH, because initially we may not have the velocity triangle so, but this these are certain values this is value of so let us psi has to be greater than 0.15 and 0.13 0.30.

So, it has to be between 0.15 from here because H value is known to us. So, we can always find the value velocity of the flow similarly peripheral velocity u by under root 2 gH. Now the Ku value is 0.6 to 0.9 it is quite high if you compare with the Pelton wheel it is quite high, anyway the rpm of the this Francis turbine or a specific is the speed of the Francis turbine is quite high in comparison if we compare it with the Pelton wheel. So, this speed ratio Ku is u by under root. So, this is how we will get the value of u, once the value of u is with us if n is with us we can always find the value of D. So, out of these informations we can find most of the dimensions of a Francis turbine.

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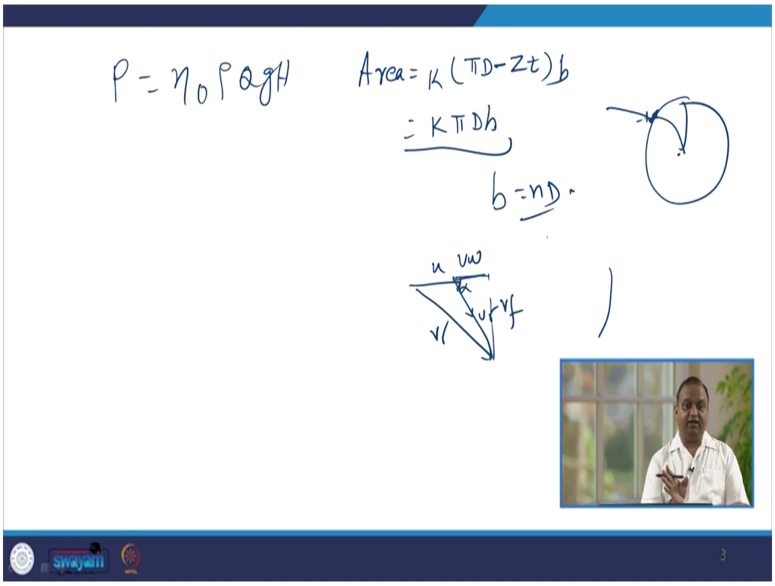

Now if you want to design a turbine then we can always say that the power delivered by the turbine is overall efficiency multiplied by rho Q gH ngH multiplied by the overall efficiency is the power delivered by the turbine. Area developed area available for the flow in a turbine in the Francis turbine is pi D minus Zt. Now t is the thickness of because on the wheel there are vanes. So, thickness of the tip of the vane in this area there will not be any flow of water, if there are z number of vanes so this much area will become ineffective.

So, actual area will be available is pi Dt multiplied by b right and a constant K. So, it can be K pi D b if we are assuming p as 0 if you are neglecting it and b we always know that b is equal to nD we have already discussed. Now with these information we can have the angles for the guide vanes also suppose we want to have guide vane angle. So, for the inlet of the francis turbine it is coming from the top right. So, so this is u, this is Vr and this is V right and this is Vf right now Vf by w Vw, this is angle alpha blade inlet angle right. So, blade inlet angle or guide vane angle is same thing, now in order to find the guide vane angle.

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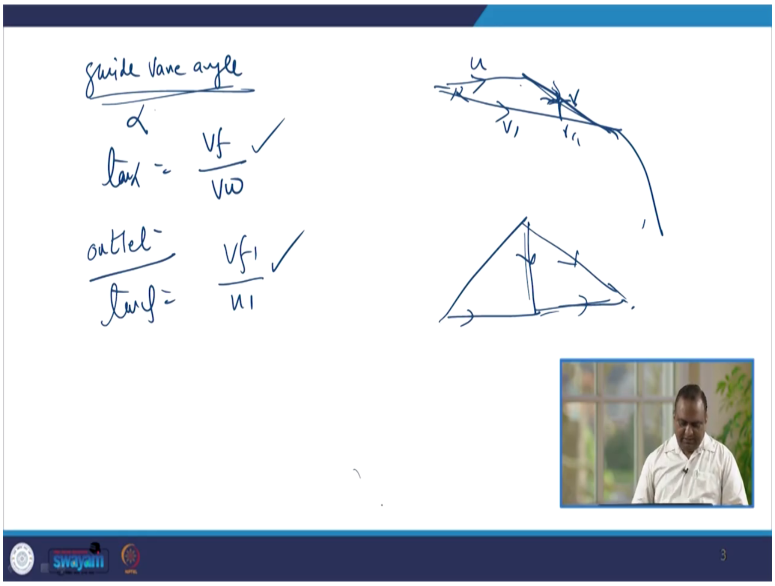

So, guide vane angle which is alpha can be taken as tan alpha is equal to Vf by Vw that can be taken from the inlet triangle because at inlet of the turbine this is this is the vane, this is Vr 1 r 1 and this is u and this is V 1 right and this is V 1 and this is alpha. So, guide vane will guide the jet in this direction V 1 direction wheel is moving with u direction and this will empower the relative velocity Vr 1 Vr in this direction Vr in this direction right.

So, this angle alpha this is guide vane angle can be calculated by Vf by w and outlet for example, outlet at outlet the angle phi similarly that angle phi can be calculated as Vf 1 by u 1 because outlet triangle is like this it has no wheel component yes. So, it is going to be like this outlet triangle is like this, it does not have any wheel component. So, the tan phi is going to be Vf 1 by u 1.

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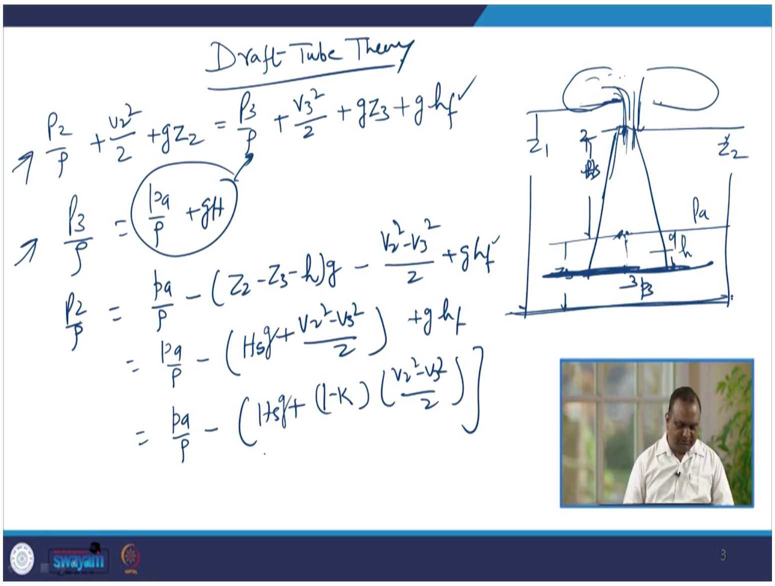

Now let us come to the draft tube, draft tube which I said is an integral almost integral part of any Francis turbine. Now what is draft tube theory, let us assume that there is a Francis turbine and fluid is moving after the radial moment it is moving in this direction and at the exit of the turbine there is a draft tube right. Draft tube is also submerged in water it is not left hanging otherwise the atmospheric pressure will come here.

So, it is submerged in water let us say it is submerged in water at the height of h, here the pressure is atmospheric pressure right and this h this height is z 3 let us say this is z 3 this is data reference value this as exit of the turbine is z 2 and inlet of the turbine is z 1 right now we will do the energy balance; so, we will apply the Bernoulli's theorem between 0.2 and 0.3 ok.

So, p 2 by rho plus V 2 square by 2 plus gz 2 is equal to p 3 by rho plus V 3 square by 2 plus gz 3 plus ghf, why I have taken ghf, because there is always friction losses when there is the movement of the fluid in actual practice there are always a friction losses. So, I have taken zf into this friction losses into the account.

Now, p 3 if you look at the p 3 by rho this is 3 sorry this is h this is 3, no this is not z 3 sorry this is this is the z 3 this is 0.3 exit of the draft tube and 2 is the inlet of the draft tube right. So, this is p 3. So, p 3 is going to be equal to this is a atmospheric pressure pa by rho plus gH pressure of this water column.

So, we have taken 2 points in a draft tube this is inlet of the draft tube which is 0.2 and exit of the draft tube 0.3 right and we have applied Bernoulli's theorem at 2 points total energy here and total energy here pressure at 3 is equal to pressure at this point plus pressure of the water column. Now if you put the value of p 3 by rho pa by rho gH here we will get p 2 by rho is equal to pa by rho minus z 2 minus z 3 minus h minus V 2 square minus V 3 square divided by 2 plus ghf, just we have put this value of p 3 by rho here and manipulated the equation right. Now p 2 by rho is equal to pa by rho minus now z 2 minus z 3 this elevation this minus elevation this is the length of the or draft tube Hs difference in the elevation.

So, Hs it is also called suction length. So, Hs suction height suction height plus V 2 square minus V 3 square by 2 plus ghf right then this is Hs length of the draft tube which is above the water level right. So, this is Hs, this is Hs which is some the length of the draft tube which is submerged in water is not taken into the account and this comes from this formula z 2 minus z 3 minus h it is obvious. So, it is Hs plus ghf and this is going to be equal to pa by rho minus Hs plus 1 minus K V 2 square minus V 3 square by 2 hf also we have taken as the change in the kinetic energy multiplied by K because the friction losses in any flow in a pipe or any passage.

They are taken as a some constant multiples there change in the kinetic energy or total kinetic energy multiplied by some constant it is a normally diverging section. So, change in the kinetic energy multiplied by K can comfortably taken as head loss due to friction right. So, V 2 is greater than V 3 always because this is diverging section. So, velocity at 2 should always be greater than velocity at 3 and it means the pressure at 2 will always be less than atmospheric pressure. So, this will increase the pressure difference and when there is a high pressure difference more energy can be extracted from the fluid, same thing happens in the steam turbines.

Steam turbines we have condenses so, in the condenses we are maintaining pressure of the order of 0.1 bar or 0.15 bar the reason being there are several reason and one of the reason is we can extract maximum energy from the fluid. So, here also if you are reducing if you are maintaining very low pressure at 2 we can extract maximum amount of energy from the flowing water, but the issue is to what extent we can reduce the pressure at 2 we cannot we get a absolutely vacuum in that case the water will start boiling.

So, normally the head at state 2 is kept around 2.5 or 2.6 right, if you reduce the head at 2 or a pressure at 2 below it, in that case the boiling of water takes place. If the temperature of the water becomes the saturation temperature of water the boiling of water takes place and when this water flows and this bubbles when they collapse it cause the cavitation. So, pressure is kept is reduce to a certain extent that the vaporization of water does not take place or bubbles are not formed.

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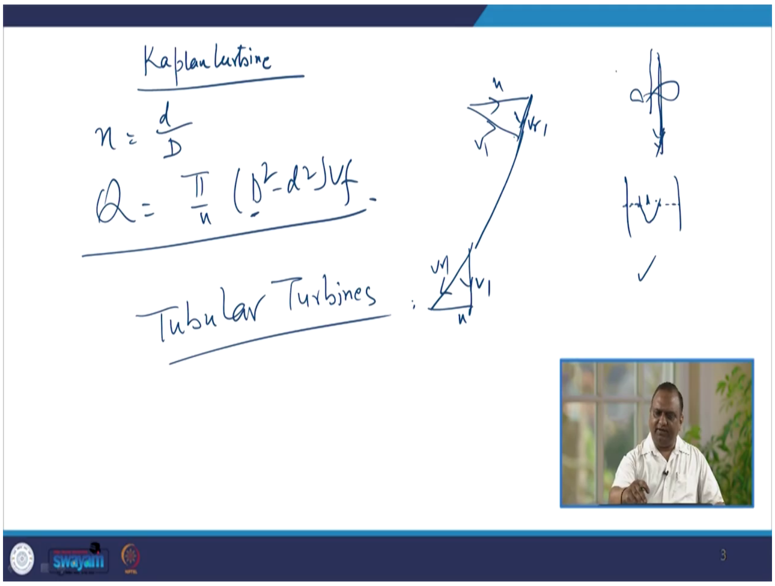

Now, we will discuss the Kaplan turbine, another reaction turbine is Kaplan turbine, Kaplan turbine is an axial turbine right. So, there is only axial there is sort of turbine blades are here and there is an axial movement of the fluid. If you draw the velocity diagram of a Kaplan turbine for the Kaplan turbine it is going to be like this is Vr 1 this is u and this is V 1 and now here this is Vr 1 u this is V 1 it is going to be like this blades are flexible. So, inlet angles can be adjusted in the Kaplan turbine it has it works on the head which is lower than the Francis turbine.

So, if we put in a chronological order. So, Kaplan turbine requires the minimum head then it is Francis turbine and then it is Pelton wheel. So, for this also it is n is equal to d by D and Q volumetric flow rate is equal to pi by 4 d square minus d square velocity of the flow. So, velocity of the flow velocity in this direction and this is the diameter of the hub. So, diameter of the turbine passage and this is the diameter of the hub and this much part is remaining through which the flow of the fluid takes place. It has casing the Kaplan turbine has casing it has 4 to 6 blades specific speed is quite high and the other quite large in size, if you compare the size of the turbines in terms of power generation suppose power generation is constant.

So, in smaller size will be for the Pelton wheel then size will increase for the Francis turbine and the larger and the highest size is going to be for the Kaplan turbine. There tubular turbines also several types of turbines. Now tubular turbines they do not have any casing scroll casing is not there and they have adjustable blades and both type of the blades adjustable blades and non adjustable blades.

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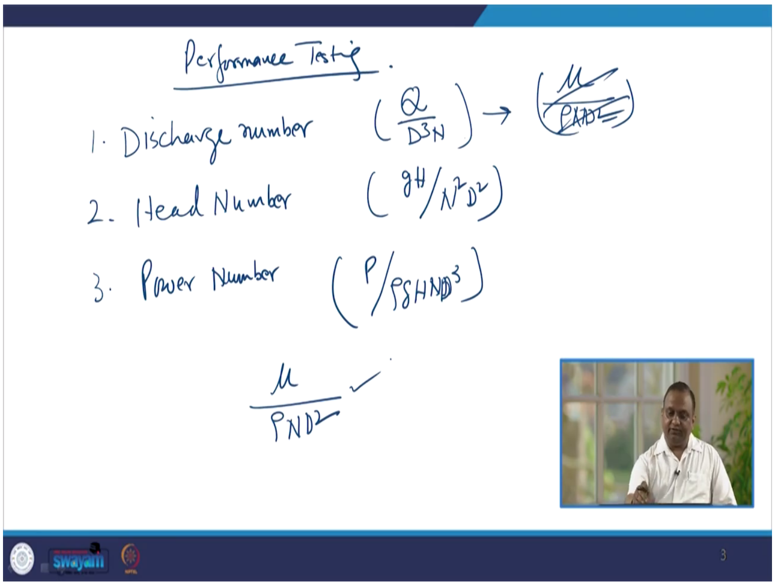

Now performance testing of turbines is very important, performance testing for the purpose of performance testing there are certain dimensionless numbers which are to be considered. For example, number 1 is discharged number it is Q by D cube N or Q by N D cube this is known as discharge number. So, if there is a prototype and the model right if in the model is same has to perform same as their discharged number should be equal.

Number 2 head number head number is gH divided by N square D square. Third one is power number, power number is p by rho gH N D cube. This is power number discharge number can also be written as mu by rho ND square mu by rho ND square.

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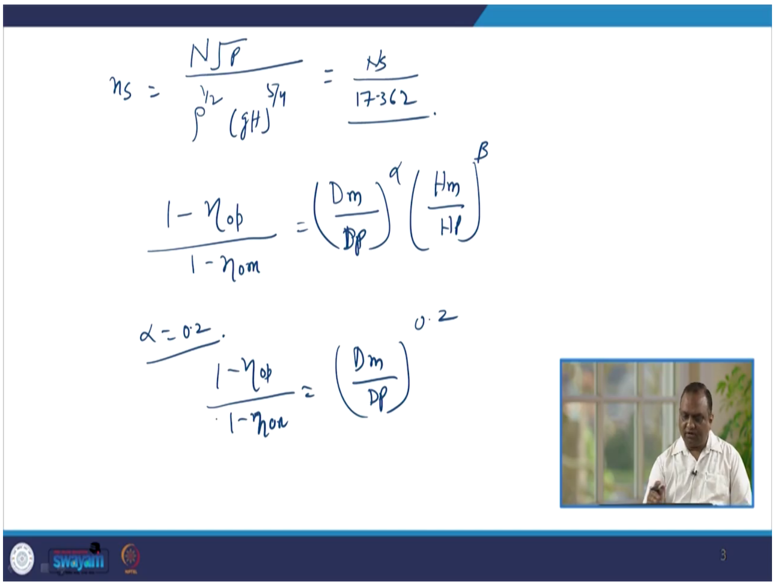

There is a dimensionless specific speed Ns right, dimensionless specific speed is N under root p divided by rho raise to power half gH raise to power 5 by 4. So, if you take the properties of water right and power you convert I mean kilowatts to the watts take the value of v 9.81 it becomes Ns by 17.362 this is the dimensionless specific speed. Now efficiency because we have scale down the dimensions the fluid properties are not changed right. So, efficiency of prototype and model may not match with each other. So, for that if there is a formula 1 minus efficiency of prototype 1 of efficiency of model is equal to prototype to power alpha Hm by Hp raise to power beta right. So, this is the moody formula where alpha is equal to 0.2 in the moody formula it is equal to Dm by Dp is equal to 0.2 right.

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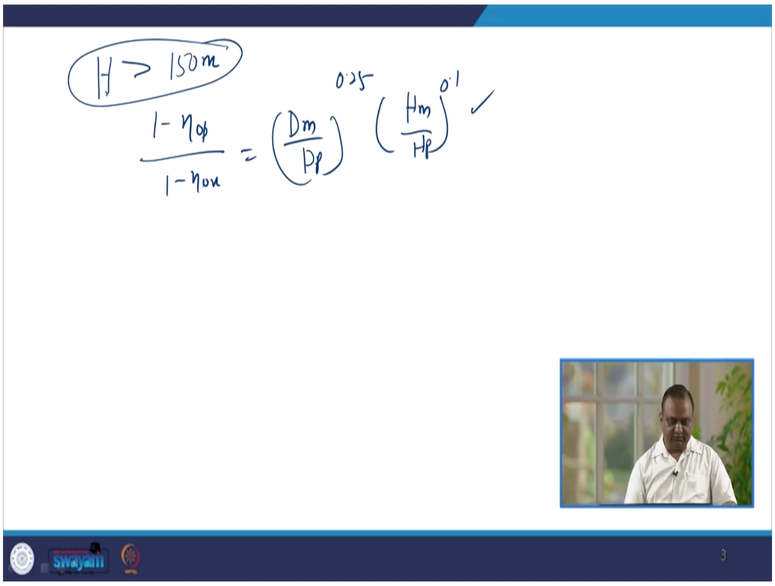

For head is greater than with the head is greater than 150 meters then mostly for the Pelton wheel or even Francis turbine also, this formula can be used when the head is greater than 150 meters that is all for today.

Thank you very much.