Steam and Gas Power Systems

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Module No # 06
Lecture No # 26
Impulse Reaction Steam Turbines

Hello I welcome you all in this course on steam and gas power systems. Today we will start discussions on impulse reaction steam turbines so far we have analyzed the impulse turbine.

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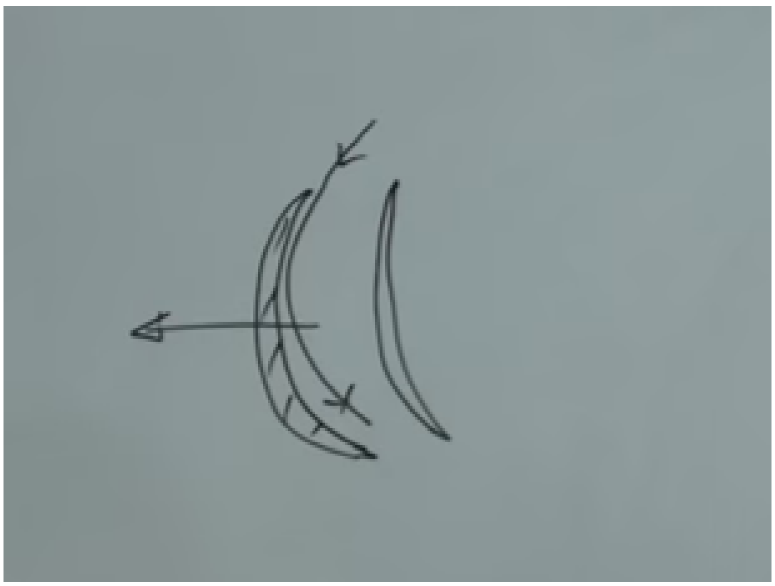

In impulse turbine the steam slides over the blade surface and due to change in the direction of the flow of the steam, the net force are exerted on the blade surface and power is developed. Now in impulse reaction turbine, the pressure drops takes place in the blade passage as well in impulse turbine. There is no pressure drop in the blade passage but, in impulse reaction turbine there is a pressure drop in the plane blade passage as well.

Due to this pressure drop additional force is exerted on the blade, so blade releases two types of forces one is due to change in momentum impulse force and another one by the reaction due to pressure drop in the passage. Now if you look at the blade outlet angle of impulse turbine. I will draw a larger figure.

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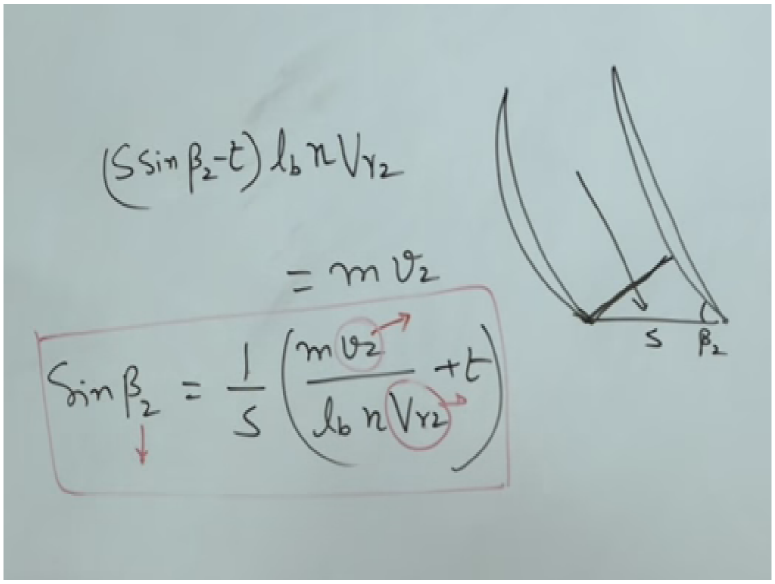

Blade outlet angle of impulse turbine this is the blade outlet angle beta 2 and the passage the opening perpendicular the flow is this much. So effectively we are using this much of space and this is suppose S, then this is S sin beta 2 this tip of the blade has some finite thickness. So this is subtracted from here multiplied by height of the blade, this is length of the blade that is perpendicular to this board.

Number of blades multiplied by relative velocity at exit via VR2 = mass flow rate and specific volume at state 2. Now from this equation we can simply find the value of sin beta 2, that is MV2 divide by length of the blade, number of the blades in on the periphery, relative velocity at the exit T will go on this side and in order to find sin beta 2, we can divide this by 1 by S.

This is for impulse turbine but in reaction turbine because there is a pressure drop, the VR2 this is specific volume at exit increases and at the same time relative velocity at the exit also increases. But the rise in relative velocity at the exit is more than the rise in the specific volume so that is why the beta 2 values in reaction impulse, reaction turbine are slightly less than this.

But this equation has to be satisfied with the modified value of specific volume and the relative velocity this equation has to be satisfied in any case. Now in impulse reaction turbine if you draw the velocity diagram for impulse reaction turbine.

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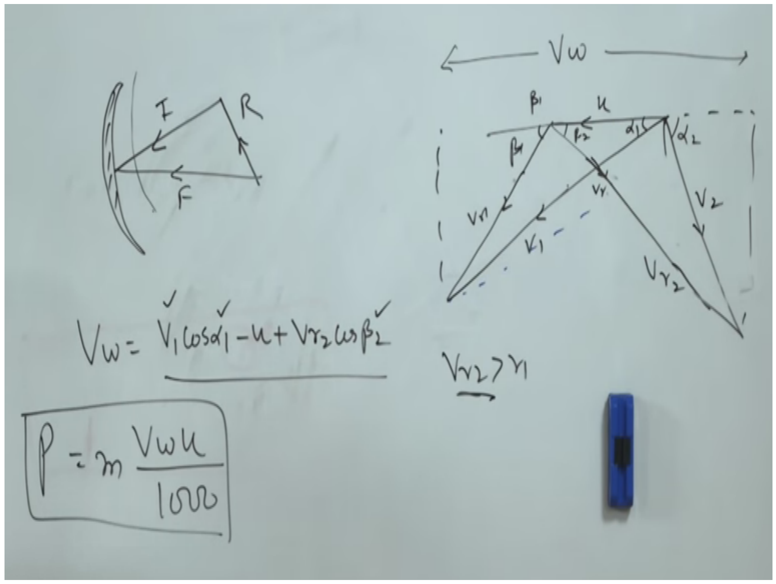

Now for the inlet conditions the diagram is going to be the same inlet condition this is VR1, this is U and this is V1 and this is blade inlet angle and this is nozzle inlet angle right. So the steam is gliding more the surface in impulse reaction turbine at same time the pressure drop is also taking place. So without pressure drop if we draw the velocity diagram then it is going to be something I will extend this one this is V1 and this is VR1.

So it is going to be something like, this is beta 2, VR2 and this is V2 right. So some impulse force is exerted on the plate that is the net force due to this effect this component, this is the net force parallel to this force is exerted on this blade. Now expansion takes place during the flow in the passage expansion of steam takes place due to this expansion the relative velocity R 2 increases and increase is significant and we get R 2 up to here this R 2 is extended and we get R 2 here.

This is actual VR 2 right and if we connect this with this one we will absolute velocity at exit. Now in reaction turbine because this is not in proportion because in reaction turbine the VR 2 is much greater than VR 1. So this has to be greater than this just a minute greater than this is VR 2 and this is V 2.

VR 2 is greater because relative velocity and exit is also increased due to change in pressure during the course of flow of steam through the blade passage. Now impulse force is works in this direction and reaction due to pressure drop works in this direction and addition to this is impulse force. This is reaction force addition to this is the net force exerted on the blade.

And if you want to have power developed in this type of turbine then for developing the power, for calculating the power developed in this turbine we will have to calculate the will component of the velocity, as we do in the case of impulse turbine. The will component of the velocity VW = V1, cos alpha 1 - U + VR 2 cos beta 2. There many ways of finding if we have the value of alpha 1 and this beta 1 and this is alpha 2.

Then by many ways we can find the will component if depending upon on the information available with us suppose, we have absolute velocity and inlet and outlet then it is going to be V 1 cos, alpha 1 + V2 cos alpha 2. If we have relative velocity at inlet and outlet then VR 1 cos alpha one and VR1 cos, beta1, VR 2 cos beta 2 right.

But normally it is taken like this because in actual practice we know in most of the cases the absolute velocity at inlet and nozzle inlet angle that is miserable I mean it is always available and blade exit angle that is why this expression is used in to find the will component of the velocity and power developed is V W U divide by 1000 multiplied by mass flow rate right.

The power developed formula is same only will component in impulse reaction turbine changes due to pressure drop in the blade passage. Since the pressure drop is taking place during the flow inside a impulse reaction turbine the specific volume of steam also increases.

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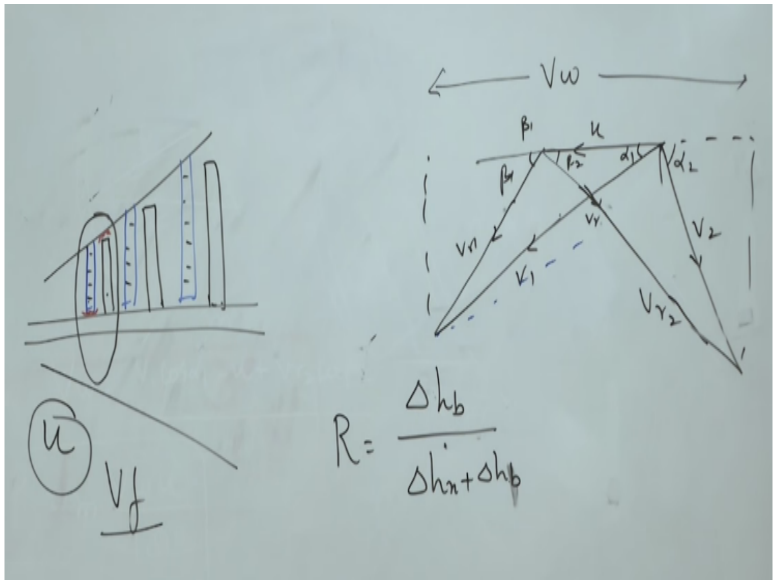

So if we look at arrangement of the blades in impulse reaction turbine on the rotor, there are moving blades. They are mounted on the rotor the moving blades are mounted and on stator fixed blades are mounted. These blades remain stationary because they are mounted on the casing only these blades rotate in a particular direction and nozzles are fixed in these blades In fact they are fixed blade patches passages.

They are treated as closure and together these fixed and moving blade row they form one stage and it is assumed that peripheral velocity remains constant during the single stage. But when there is an exhale movement of the steam and it is ensured while designing the turbine that velocity of flow or exhale velocity remains constant. So the specific volume of the steam is increasing while flowing along the axis of the turbine.

The cross section area is increased in order to maintain constant velocity of flow. Now because the pressure drop is taking place in fixed blade and moving blades right and the power developed. So some of the power is lost in this turbine due to leakage because there is a always a gap between here and here. So this movement of the steam does not participate in power development.

So this is a loss in the power but it cannot be completely avoided because we cannot seal both the sides otherwise will be no movement of the rotor. So there is a term degree of reaction is enthalpy drop in rotating blades or enthalpy drop in the blades and total enthalpy drop in a stage means a stage consists of row of inside the moving blades. So we can always write the degree of reaction as delta HN + delta HB enthalpy drop in closures and enthalpy drop in blades.

So for a pure reaction turbine the degree of reaction is one, there is no enthalpy drop in nozzles right. But normally the turbines are impulse reaction turbines, because when there is a change in the direction of the motion of steam it will exert force on the blades. So the turbine it is an impulse reaction turbine. Now we will do elaborate analysis of degree of reaction.

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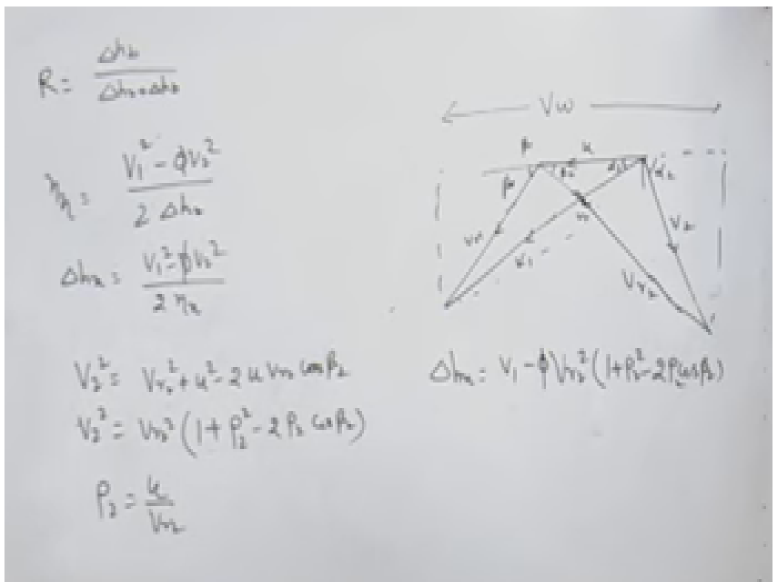

Now degree of reaction is Delta H B, divided by Delta HN + Delta HB. Now efficiency of the nozzle = V1 square - phi V2 square, by 2 Delta H nozzles right. Phi is the carry over coefficient, so Delta HN = V1 square – phi V2 square by 2 efficiency of the nozzle. Now V2 square, this 1 is V2 square is VR 2 square.

If we consider this triangle then it is VR2 square + U square - 2 UVR 2 cos beta 2 right and if we take VR2 square common, then V2 square = VR 2 square. 1 + rho 2 square - 2 rho 2 cos beta 2. Now rho 2 is U, by VR 2. Now from here if you are putting this value here in this equation, we will get Delta H N or enthalpy drop in the nozzles = V1 - 1 + rho 2 square VR 2 square, 1 + rho 2 square -2 rho cos beta 2.

This is rho 2 the enthalpy drops in the nozzle. Now in impulse reaction turbine it is assumed that, this efficiency of the nozzle is equal to the efficiency of the blades. So if we write expression for efficiency of the blades.

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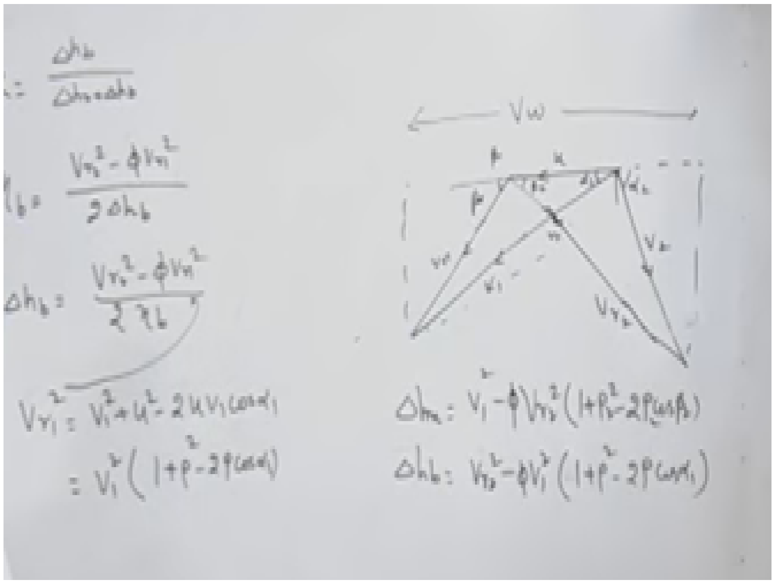

That is going to be = VR 2 square - phi VR 1 square by 2 Delta H B. So enthalpy drop in the blade is VR 2 - phi VR1 square by 2 efficiency of the blades. Now VR 1 square, if we reform this triangle then VR1 square is V1 square + U square - 2 UV 1 cos alpha 1 right. Now here if we take 1 square out then it is 1 + rho square - 2 rho cos alpha 1.

Now putting this value here VR1 here we will get Delta H VS VR2 square. So this is V1 square, so VR2 square - phi V1 square 1 + rho square - 2 rho cos alpha 1. Now we have enthalpy drop and across the nozzles and enthalpy drop across the blades and while putting this value together we can find the degree of reaction of rate turbine impulse reaction. Now for impulse reaction turbine there is a special type of turbine which is known as Parsons Turbine.

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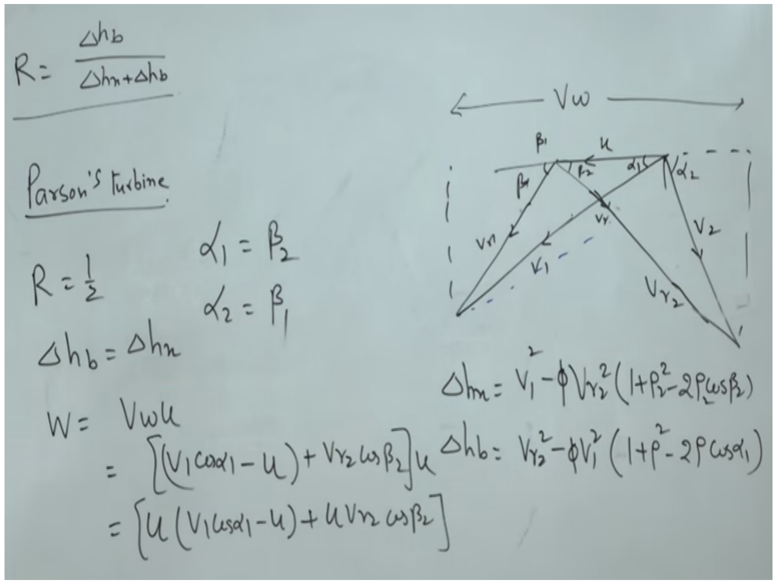

In parsons turbine the degree of reaction is half, when degree of reaction is half or 50 % then enthalpy drop in blades is equal to enthalpy drop in nozzles. Only in that case the R, is going to be half once degree of reaction is half there is another characteristics of Parsons Turbine nozzle is inlet angle is equal to blade outlet angle and nozzle outlet angle is equal to blade inlet angle right.

And now based on the characteristic of Parsons Turbine we will solve one numerical on Parsons Turbine because in this lecture I was supposed to include impulse reaction turbine, degree of reaction we have already discussed. Now generalized equations we have discussed on degree of reaction.

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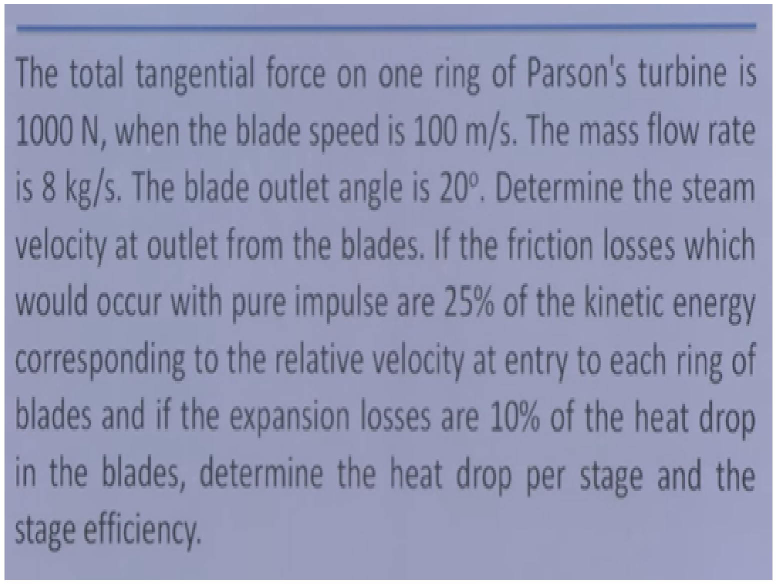

Now a numerical based on Parsons Turbine now in this numerical the total tangential force on one ring of Parsons Turbine is 1000 Newton, when blade speed is 100 meters per second the mass flow rate is 8 kg per second. Blade speed means U this U, is 100 meter per second the blade outlet angle is 20 degree.

Determine the steam velocity at outlet from the blades if the friction loses which would occur with pure impulse are 25% of the kinetic energy corresponding to the relative velocity at entry to each ring of the blades and if expansion losses are 10 % of the heat drop in the blades determine the heat drop per stage and stage efficiency. So heat drop per stage and gross stage efficiency has to be calculated.

Now gross stage efficiency is the work developed in the stage and the heat drop in the stage that is the gross stage efficiency. If we refer this, so W = V W and U this is per kg per second flow of steam the work is VWU and V W U is V1 cos alpha 1 - U + VR 2 cos beta 2. Now V1 cos alpha 1 - U + VR 2 cos beta 2 now if we multiply this by U, we will be getting the output right. So it is U multiplied by V1 cos alpha 1 - U + UVR 2 cos beta 2 right further W is equal.

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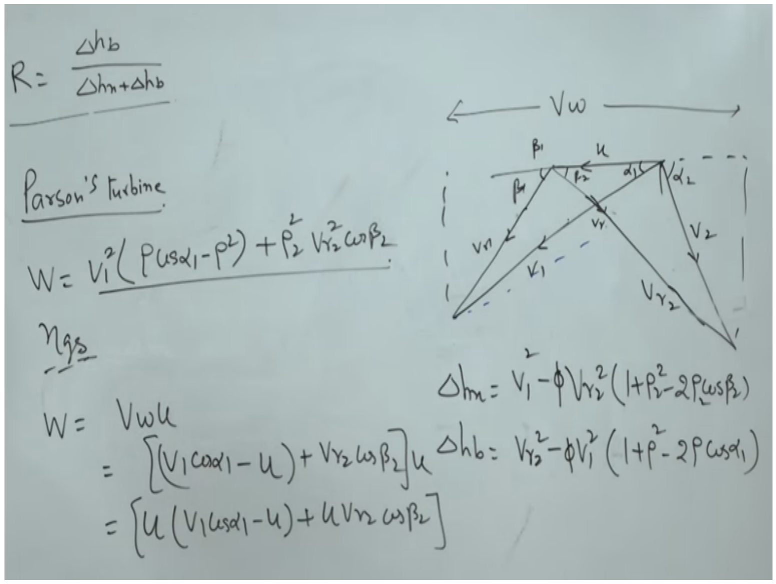

So W = U = rho V1. So it is going to be = V1 square rho, will go inside rho cos alpha 1 - rho square + rho 2 square VR2 square cos beta 2 right. Now this is the output and we have the enthalpy drop per stage and this will give the gross stage efficiency that is output of the turbine divided by the enthalpy drop. Now in Parsons Turbine because the things become simpler because beta 1 = alpha 2 and alpha 1 = beta 2.

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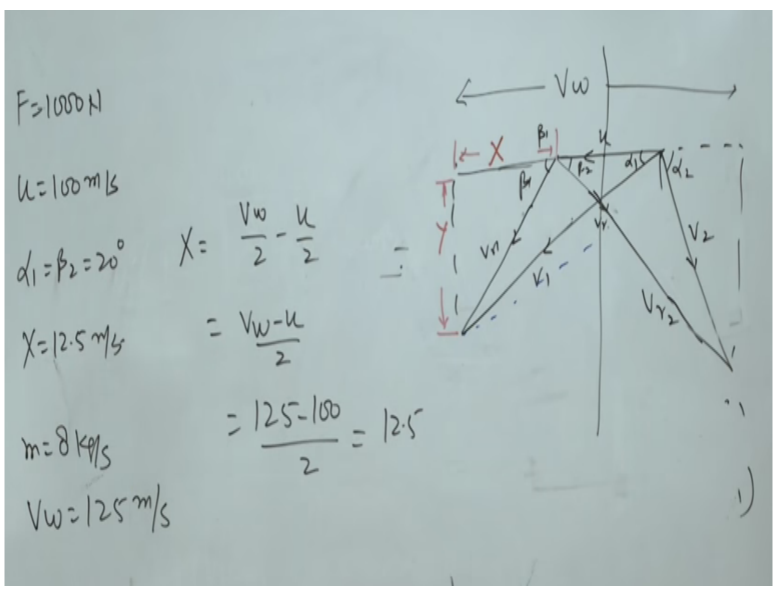

Now in this numerical we will start with force exerted of blades is thousand Newton right and U = hundred meters per second alpha 1 = beta 2 = 20 degree it is given here blade outlet angle. So blade outlet angle automatically becomes this nozzle inlet angle for Parsons Turbine. So F force is VWU because it is given in Newton, will not divided by thousand. So this is work so force is MVW right VW is not with us. Mass flow rate is given here is 8 per second.

So mass flow rate is 8 kg per second, so force is 1000 Newton divide by 8 will give VW. So VW here is 125 meters per second this is 1000 by 8. Now if we look at the velocity diagram for Parsons Turbine because these angles are equals both sides and the middle of the peripheral velocity vector both sides are same. So if we take this X and this is suppose this is Y, X is this much and this is Y.

So X is VW by 2 - U by two or V W - U by 2 V, VW is 125 and U is 100 divide by 2 and it is going to be 12.5. So X is 12.5 and Y. Before we take Y we can take Y as this X + U, Y = or Y = X + U 10 alpha 1. Because we have the value of alpha 1 only, we do not have value of beta 1.

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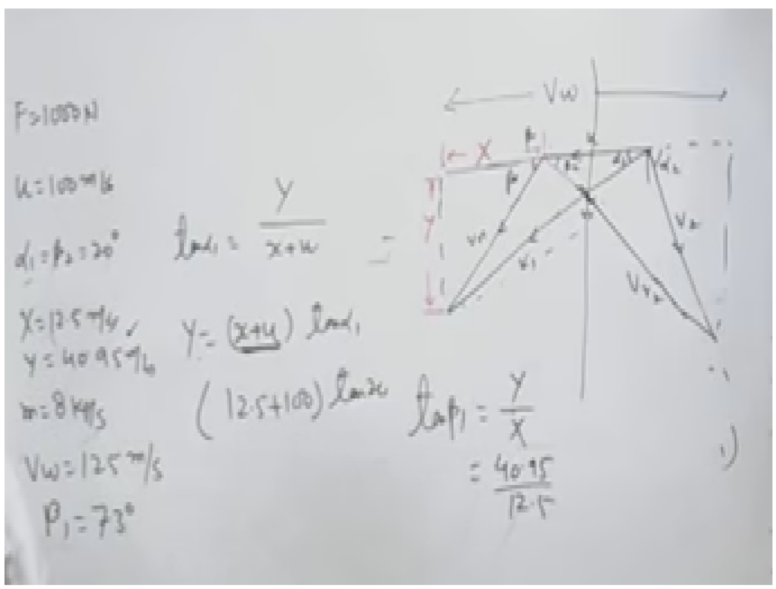

So 10 alpha 1 it is going to be = Y divided by X + U.Y = X + U 10 alpha 1. If we take X + U the X is V W - U by 2 + U. So X is this expression is VW + U by 1, 10 alpha 1 Y. Now Y = X + U 10 alpha 1 X we have already calculated 12.5 U, is 100, 10, 20 and this will give the value of Y as 40.95 meters per second.

Now once we have the value of Y and value of X then 10 beta 1 = Y by X or = 40.95 divided by 12.5. From here we will of the value of beta 1 and the beta 1 is 73 degree okay.

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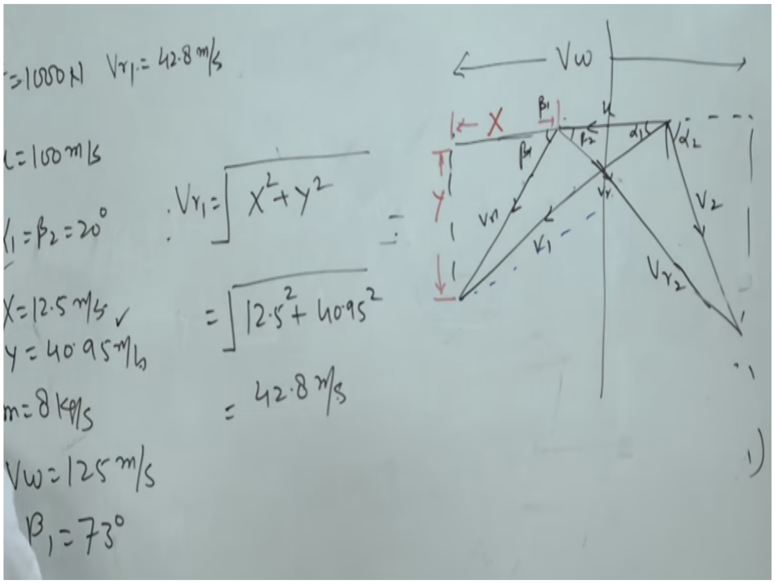

Now with the help of this information we can find the value of VR 1 also VR 1 is under root X square + Y square and this under root X square + Y square is under root 12.5 square + 40.95 square and this is 42.8 meters per second. So VR 1 is 42.8 meters per second.

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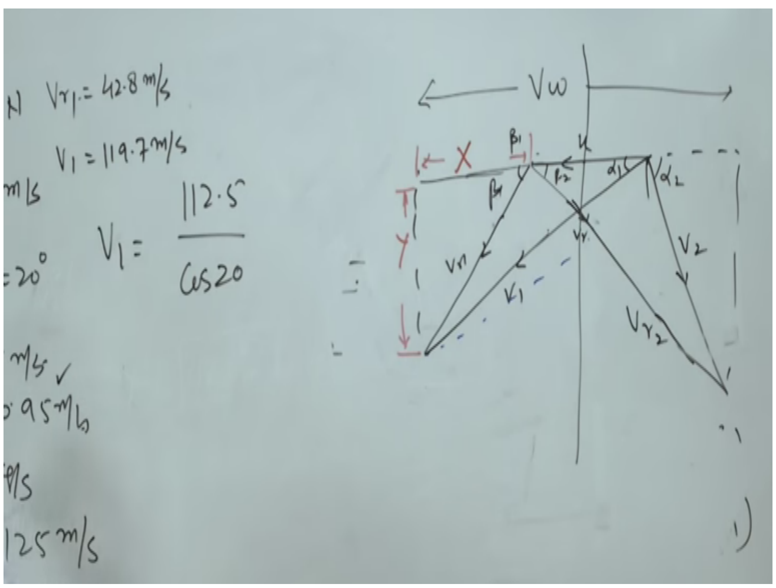

Now VR 1 is with us now in order to find V1 V1 is 112.5. We have already calculated this length 112.5, divided by cos alpha 1. Alpha1 is cos 20, so V1 also is determined from here that is 119.7 meters per second.

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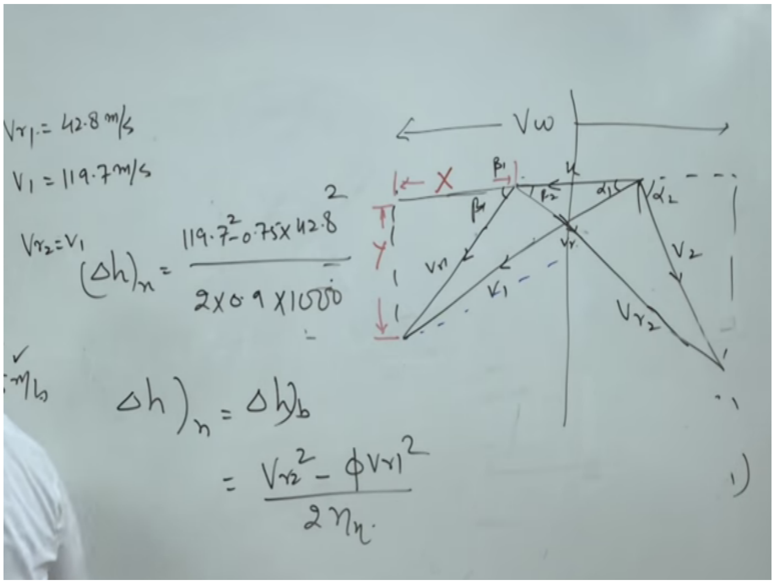

Now pressure enthalpy drop in nozzle that is isotropic enthalpy drop in the nozzles and there is equal to enthalpy drop in the blades. Because it is a Parsons Reaction turbine, so the enthalpy drop in a stage is equally divided between the enthalpy drop in nozzles and enthalpy drop in the blades and that = VR2 square - phi VR1 square, divide by 2 efficiency of the total right. And VR1 is given here and VR2 = V1. VR 2 = V 1.

So enthalpy drop in nozzle is 119.7 square – 0.75, multiplied by 42.8 VR1 yes 42.8 square, divided by two times efficiency of the nozzle that is losses are 10%. So efficiency of the nozzle is 90% into 1000 to convert work into the joules into the kilo joules.

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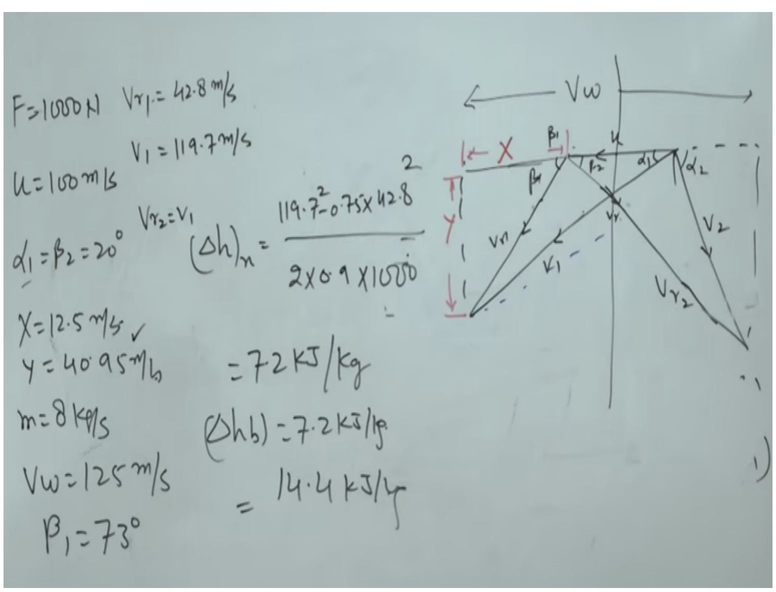

And this is 7.2 kilo joules per kg this is as per the nozzles and steam enthalpy drop will take place in the blades as well. So Delta HB is also 7.2 kilo joules per kg. So enthalpy drop per blade per stage is twice of this. So that = 40.4 kilo joules per kg. Now we have to find stage efficiency, so stage efficiency is output divided by enthalpy drop.

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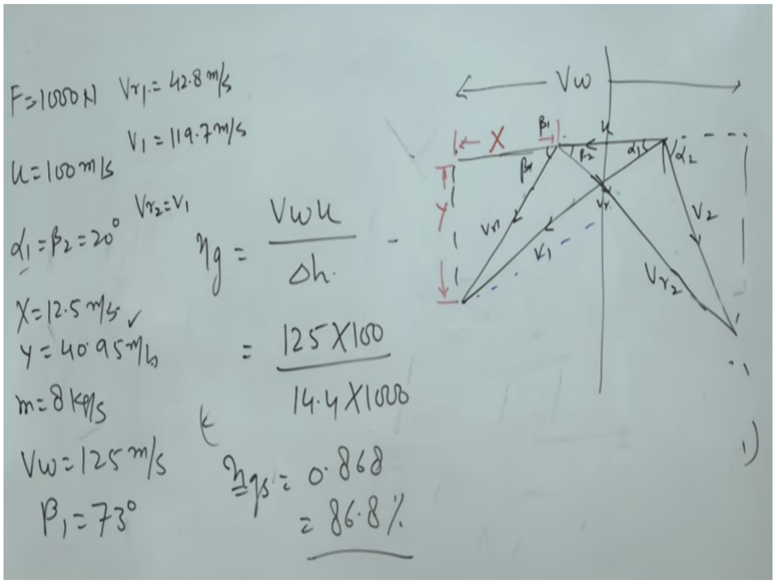

Now this stage efficiency is VWU divided by Delta H in the stage. V W is will component and U is the velocity right. So the will component is 125 and U is hundred and divided by the enthalpy drop that is 14.4. This enthalpy drop is in kilo joules and this is in joules. So this has to be converted into the joules and this will give us the gross stage efficiency.

As 0.868 or 86.8 % so we have determined in this numerical we have derived all the values which were required in this numerical and that is all for today in the next class, we will continue with the Impulse Reaction Turbine thank you.