Steam and Gas Power Systems

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Module No # 06
Lecture No # 27
Impulse Reaction Steam Turbine Performance

Hello I welcome you all in this course on steam and gas power systems and today we will discuss impulse reaction steam turbine performance and we will focus on mainly parson turbine because it is really mainly it is used as impulse reaction turbine. So gross stage efficiency of parson turbine diagram efficiency of parson turbine will drive and then we will do one worked example.

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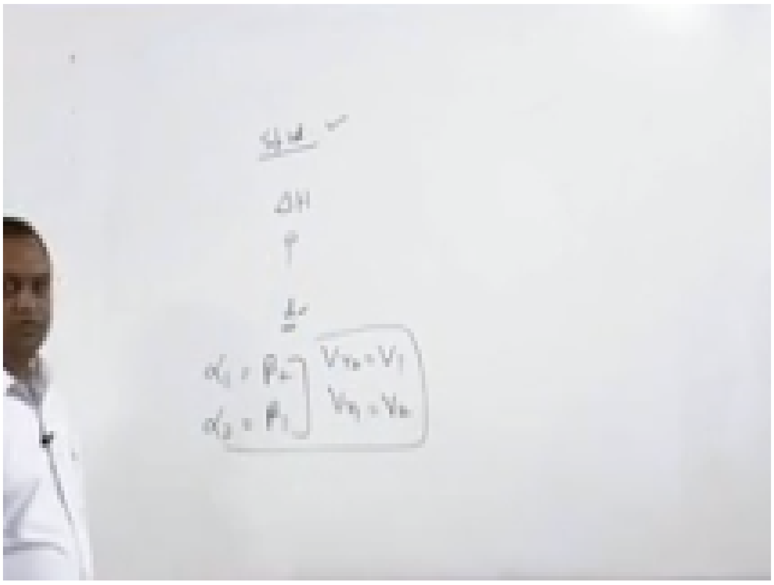

Now in a parson turbine there is a pressure drop in the nozzle and the stage as well that is why there is a increase in specific volume in subsequent stages this also helps us in right. So there is a increase in specific volume and subsequent stages delta H is also not constant in all the stages mainly it keeps on increasing in subsequent stages of parson turbine.

The value of rho it also does remaining in constant for all the stages it also varies from stage to stage that comes into the picture when we design the parson turbine. And mean diameter of fixed and the moving grades is same for a particular stage that remains constant for a particular stage.

So in a parson turbine i already explained that the nozzle inlet angle is equal to blade outlet angle and nozzle outlet angle is equal to blade inlet angle outlet relative velocity is equal to absolute velocity at inlet and relative velocity at inlet is equal to absolute velocity at outlet. So these are the conditions for parsons reaction turbine we will start with gain.

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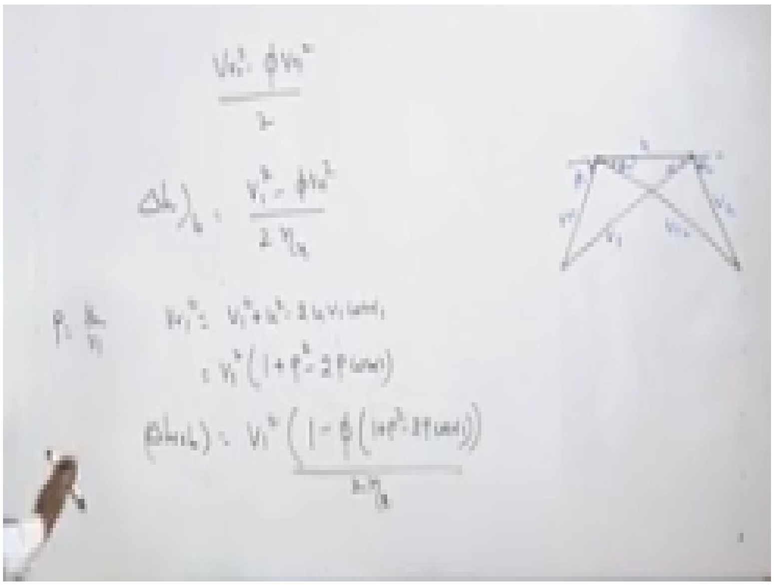

In the kinetic energy moving blades in moving blades the gain in the kinetic energy is VR2 square - K square VR so instead of K square we will take five carry over coefficient 5 VR1 square by 2. So this enthalpy in blades stage in enthalpy blades is going to be VR2 we can always write V1 square - 5 VR 1 square by 2 efficiency of the nozzle or efficiency of the blade both are same.

Now here VR1 square now let us draw the velocity diagram also because frequently we will have to give the difference of velocities. In parsons turbine it is similar so this is blade inlet angle, blade outlet angle, nozzle inlet angle, nozzle outlet angle right this is V1, VR1, VR2, V2 and this is U now here VR1 in square. So VR1 square again it is V1 square + U square ok.

It is V1 square + U square - 2 U V1 cos alpha right. So now here we take out this V1 square 1 + U by V1 is rho. So rho in square - 2 rho cos alpha 1 because rho is U by V1 peripheral velocity and is a ratio of peripheral velocity and the absolute velocity of steam which is entering the turbine.

So delta H played is V1 square and we will put the value here 1 - 5 times 1 + rho in square - 2 rho cos alpha 1 divided by 2 efficiency of nozzle this is enthalpy drop in the blades and same is the enthalpy drop in the nozzles we multiply this by 2 we will get the enthalpy drop in the stage or if we remove 2 from here we will get enthalpy drop in a stage except for the first stage.

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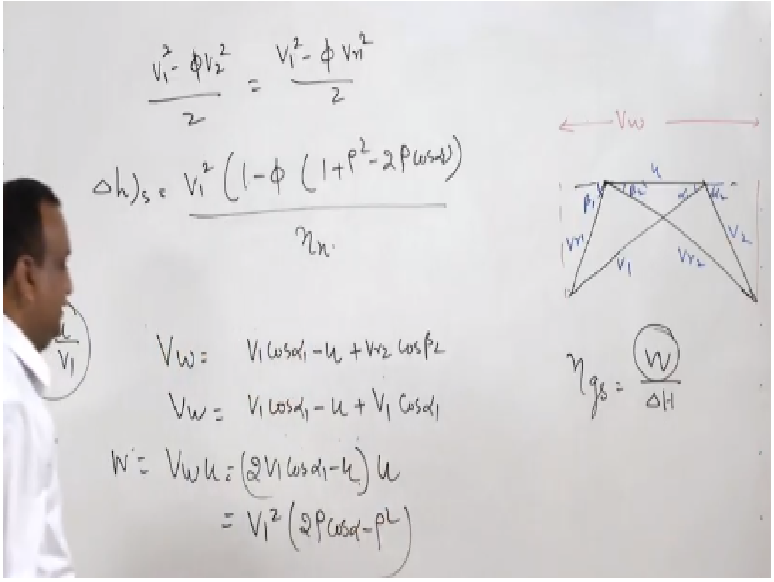

The gain in kinetic energy in each of fixed moving blade is V1 in square -5 V2 square by 2 = V1 square – 5, VR1 square by 2 except for the first stage. So delta H in a stage is twice of this so it is V1 square 1 – 5, 1 + rho in square - 2 rho cos alpha 1 divided by efficiency of the nozzle ok.

Now we want to find the gross stage efficiency now for gross stage efficiency if you remember efficiency for the gross stage need work and then change in enthalpy. Now in order to find work we need will component of the velocity ok.

Component VW of the velocity is again will refer this figure we will refer this figure this is will component VW right now this is several ways we will express it but we will take here as V1 cos alpha 1 this will 1 cos alpha 1 - U + VR2 cos beta 2 right now we one cos alpha 1 we will take as it is - U + VR2 can always be replaced by V1 in parson turbine.

So it is V1 again beta 2 can be replaced by alpha 1 so VW is this much or we can write 2 V1 cos alpha 1 - U work is VW U. So we will multiply this by U and we will replace U = rho V1 and when we replace this = rho V1 we will get V1 square 2 rho cos alpha 1 - rho square now we will write the expression for gross stage efficiency for parson turbine the gross stage efficiency is going to be V1 square 2 rho cos or we will write somewhere here.

V1 square 2 rho cos alpha 1 - rho square rho so gross stage efficiency is W by delta H per unit kg so per unit kg of mass flow rate so this is divided by this and give us gross stage efficiency right. And we can further suimplify this by just putting gross stage efficiency is equal to efficiency of nozzle then this will be cancelled out right and divided by 1 - 5 divided by 2 rho cos alpha 1 - rho in square + 5.

If you look at it here 2 rho - cos alpha one rho in square 2 rho cos alpha 1 - rho in square. So if we take this minus inside it will become 1 – 5- rho in square + 2 rho cos alpha 1 - 5 we have taken as one expression so 1 - 5.

So this is nothing but 1 – 5 + 5 2rho cos alpha 1 - rho in square right. So when this is replaced by this 1 and when we divide numerator into denominator by 2 rho cos alpha 1 - rho in square we get this expression. So this is the final expression for gross stage efficiency now in this expression the gross stage efficiency is going to be the maximum in the case when this has maximum value because efficiency of the nozzle is fixed this is fixed this is also fixed only thing is remaining this.

So this has to be maximized or Z = 2 rho cos alpha 1 - rho in square this has to be maximized with respective rho. So DZ by D rho = 2 cos alpha 1 – 2 rho = 0 or rho = cos alpha 1. Impulse turbine it was cos alpha 1 by 2 if you remember here it is cos alpha 1 ok twice of that. So now we can put rho = cos alpha 1 here now when we are putting rho = cos alpha 1.

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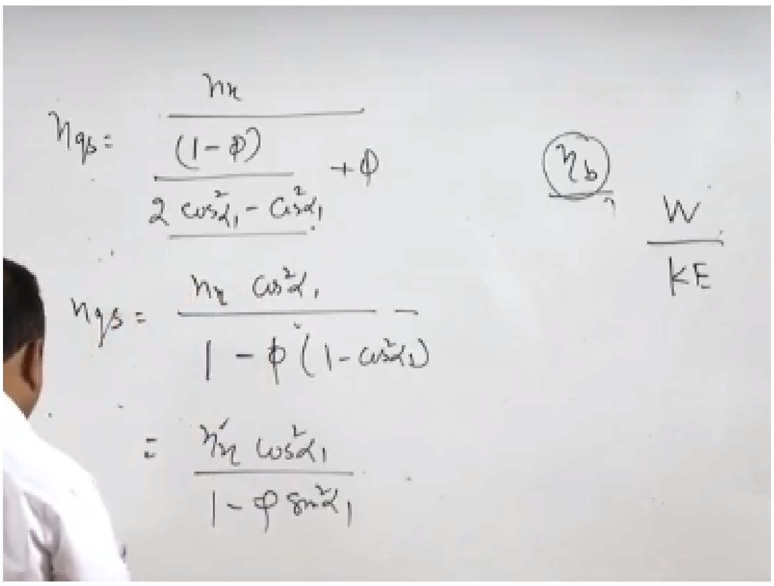

Efficiency gross stage is equal to efficiency of the nozzle 1 – 5 by 2 cos alpha 1 square - cos square alpha 1 right + 5 and this will give gross stage efficiency as efficiency of the nozzle cos square alpha 1 because this is going to be the cos square alpha 1 divided by 1 – 5, 1 - cos square or cos square alpha 1 by 1 - 5 sin square alpha 1.

This is the gross stage efficiency of impulse reaction turbine and parson type it means if we know the blade inlet angle we can find the gross stage maximum gross stage efficiency right and of course we too have the value of the efficiency of the nozzle or efficiency of the blade stage.

After gross stage efficiency we will write blade efficiency or diagram efficiency both are same right for blade efficiency we need work and kinetic energy at inlet. So first of all we will calculate the work and then kinetic energy.

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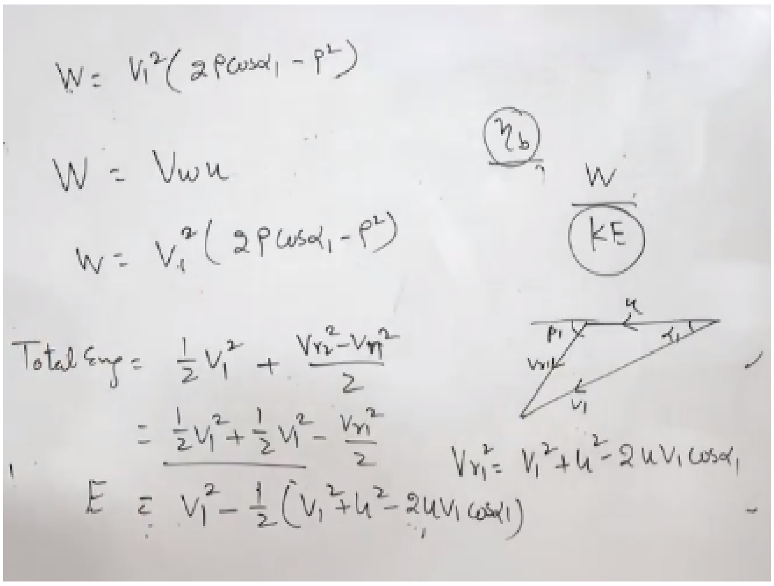

So in parson turbine per kg of mass flow rate work is like other turbines VW U right and W = V1 square 2 rho cos alpha 1 - rho square this we have already done in previous case right. Now do it again so this is the work done we do not have expectation for kinetic energy. Now the kinetic energy is the total energy = half V1 square the kinetic energy which is entering the blade and change in kinetic energy VR2 square – VR1 square by 2 right.

So W we are taking as it is V1 square 2 rho cos alpha 1 - rho square right and total energy is this much. Now here you can see that VR2 = V1 so we can always write half V1 square + half V1 square - VR2 square by 2 so they are going to be added. So it is V1 square - VR1 square by 2 now VR1 if you look at the velocity diagram this is V 1 VR1 U then this is beta 1 this is alpha 1.

So VR1 in terms of V1 and U is going to be this is VR1 in square = V1 square + U square - 2 UV 1 cos alpha 1 right and same thing we will write here. So instead of VR1 square by 2 we will write half V1 square + U square - 2 U V1 cos alpha one that is the total energy E kinetic energy

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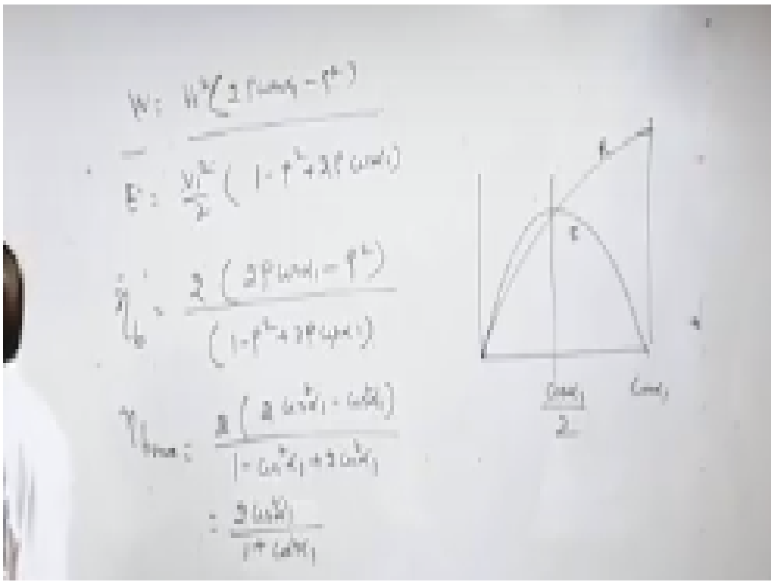

Now after this we will write the total energy as V1 square by 2, 1 - rho e square + 2 rho cos alpha 1. So this is the total energy which is entering the blade so the blade efficiency is going to be ratio of these two and it is going to be equal to when we take ratio of these two this will be cancelled out and we will get two blade efficiency 2 rho cos alpha 1 - rho in square divided by 1 - rho in square + 2 rho cos alpha 1 right.

Now here also if you put rho = cos alpha 1. So maximum blade efficiency max is going to be two times 2 cos square alpha 1 - cos square alpha 1 divided by 1 - cos square alpha one +2 cos square alpha 1 and this is going to be = 2 cos square alpha 1 divide by 1 + cos square.

So this is the maximum efficiency of grade efficiency of parson turbine now here if we compare the efficiencies of impulse reaction and impulse turbine then on the X axis if you take Cos alpha 1. So the maximum efficiency for impulse turbine is like this here it is going to be the maximum cos alpha 1 by 2 and this is cos alpha 1.

But here in this case reaction turbine it is going to be like this here it is going to be maximum this is for the reaction turbine and this is for impulse turbine right now after this we will solve we will do one worked example for parson turbine and not a parson turbine this time taken this is not a parson turbine ok.

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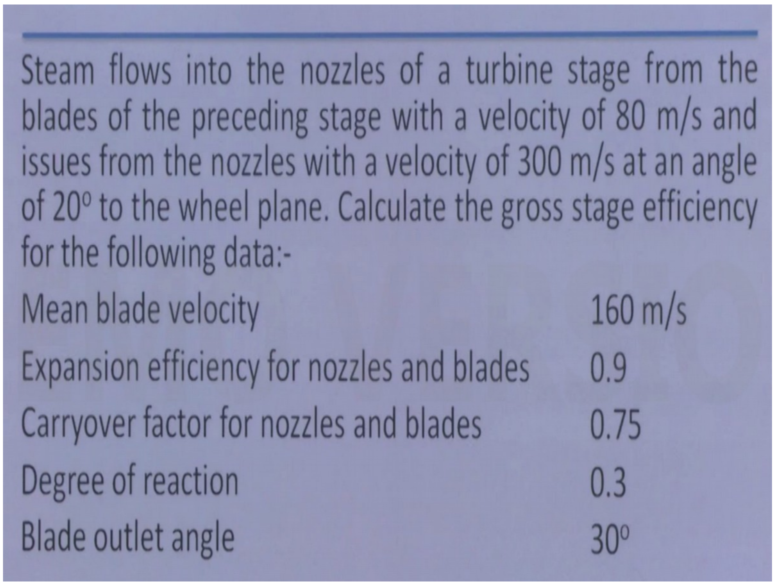

So we will do one worked example on this reaction turbine impulse reaction turbine a steam flows the problem statement is the stream flows into the nozzle of the turbine stage of the blades from the proceeding stage. So it is not the first stage right so the blades on the preceding stage with the velocity of 80 meters per second and issues from the nozzle with the velocity of 300 meters per second.

So 300 meters per second is the absolute velocity which is leaving the stage and 80 meters per second is the absolute velocity with which the steam is entering and angle is 20 degree to the wheel plane calculate the gross stage efficiency for the following data mean blade velocity is 160 metre per second. So the U of the mean blade velocity 160 meters per second so we will take them one by one.

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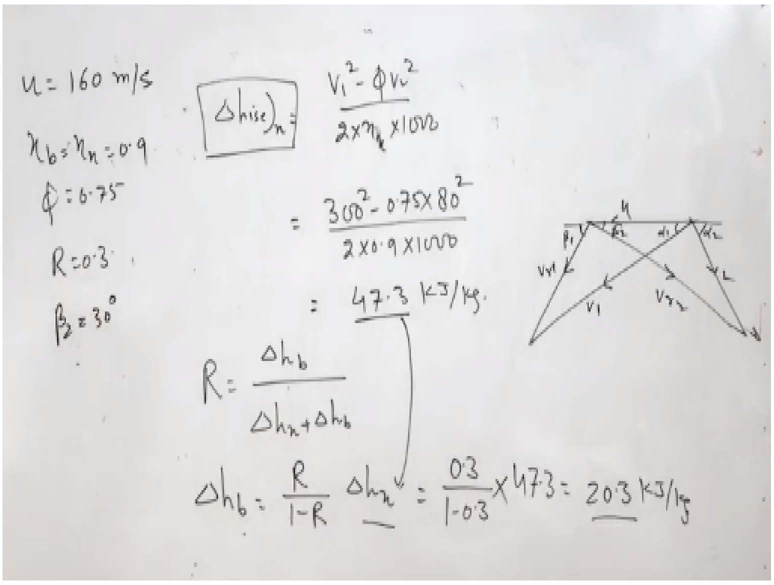

U = 160 meters per second right and expansion efficiency for nozzle and blade is 0.9 carry over factor that is 5 nozzle = 0.9 carry over factor is 0.75 degree of reaction is zero is not a parson turbine. Because here the degree of reaction is0.3 it is a reaction turbine but it is not parson reaction turbine blade outlet angle that is beta 2 = 30 degree as usual we will draw first .

We will draw the velocity diagram this is V1, VR2, U, VR2, V2 beta 1, beta 2, alpha 1 and alpha 2 right. Now delta H isotropic in nozzles = V1 square - 5 V2 by 2 into 1000 it is efficiency of the nozzle here is figures V1 is how much 300. So it is 300 square – 0.75 into 18 square divided by 20.9 into 1000 and that will give 47.3 kilo joules per kg because mass flow rate is not note.

Mass florate is not given here so we will take kilo joules per kg this is enthalpy drop nozzles R is enthalpy drop in blades divided by enthalpy drop in nozzles enthalpy drop in blades or enthalpy drops in blades is going to be = R by 1 - R delta H joules so here we have enthalpy drop in the nozzle. So this enthalpy drop can be taken here R is given 0.3.

So R we will take from here and will get 0.3 divided by 1 – 0.3 multiplied by 47.3 and that will give 20.3 kilo joules per kg that is the enthalpy drop in the stage. So here you can say because the degree of reaction is less than .5 enthalpy drop in nozzles is more than enthalpy drop in blades.

In fact it is more than two times enthalpy drop in nozzle is two times than enthalpy drop in blades.

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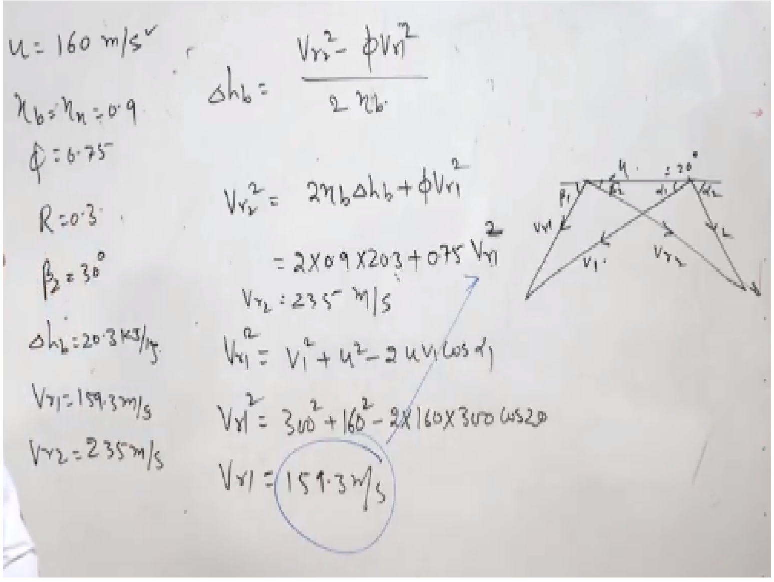

So once enthalpy drop in the blade fix with us 20.3 kilo joules per kg once the enthalpy drop in the blades is with us that is delta H b that = VR2 square - 5 VR1 square divided by 2 efficiency of the blades. Now here again we will take VR2 square, VR2 square is we will take from here itself = 2 delta H b + 5 VR1 square from this expression we can get the value of VR2 it is two times efficiency of the nozzles 0.9 delta H b we have calculated 20.3 + 5 is 0.75.

What about VR1? VR is not known to us but we have the value of VR1 square we will write VR1 square but VR1 is not known to us so what we will do we will take this triangle again we have the value of U with us V have the value of V1 and we have the value of U we have the value of alpha1 also this is 20 degree we have the value of alpha1 also at an angle 20 degree right.

So we will take VR1 square = V1 square + U square - 2 U, V1 cos alpha 1 now V1 is 300 + U1 is 160 square - 2 into 160 into 300 cos 20 and that is VR1 square and then VR1 is 159.3 meters per second VR1. So VR1 is 1 59.3 meters per second.

Now VR1 we can use here and we can find the value from here we can take the value of VR1 and put this value here and then we can get the value of VR2 as 326 meters per second. Sorry it is 325 meters per second now we have the value of VR2 we have the value of V1 and we have the blade outlet angle beta 2 value also be the same now we can find the value of VW.

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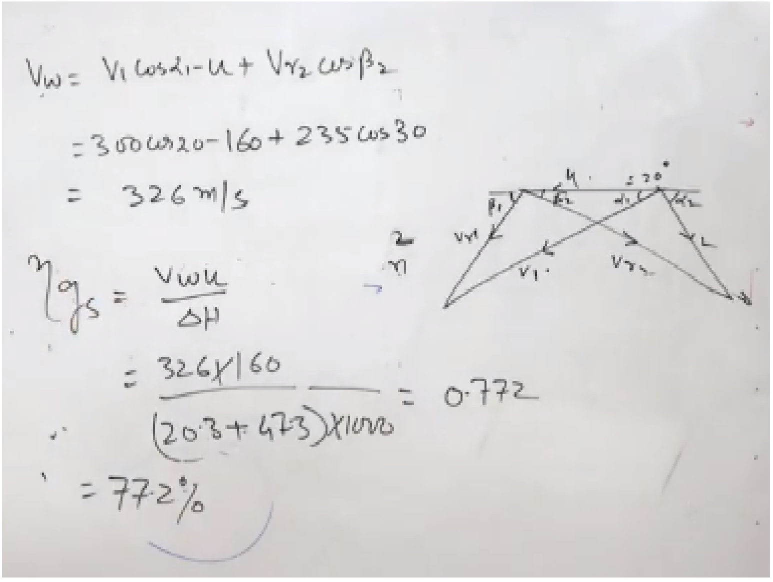

Now VW is will velocity will velocity is we can take V1 cos alpha 1 - U + VR2 cos Beta 2 this will give the will component. Now V1 is 300 cos 20 - U is 160 meters per second - 160 + VR2 is 265 cos beta 2 now the blade outlet angle is 30 degree right. Now this will give the value of will velocity as 326 meters per second and this is VW 326 meters per second.

Once we have the will velocity we can find the work multiplied this VW with U will get the work and enthalpy drop in the stage. So gross stage efficiency it is going to be = VW U divided by delta H. So 326 multiplied by one sixty divided by delta H is 20.3 this is delta H in blades and delta H in nozzles is 47.3 multiplied by 1000 because this is in volts right sorry this is in joules and so this is in kilo joules per kg.

So this gives the efficiency as 0.772 or the gross stage efficiency is turbine is 77.2 % right. So this is all for today in the next class we will start with the losses in steam turbines thank you very much.