Power Plant Engineering
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Lecture – 15
Impulse Steam Turbines

Hello, I welcome you all in this course on Power Plant Engineering. Today, we will discuss about the Impulse Steam Turbine.

Now, impulse system steam turbine is one of the turbine which is used in power plants.

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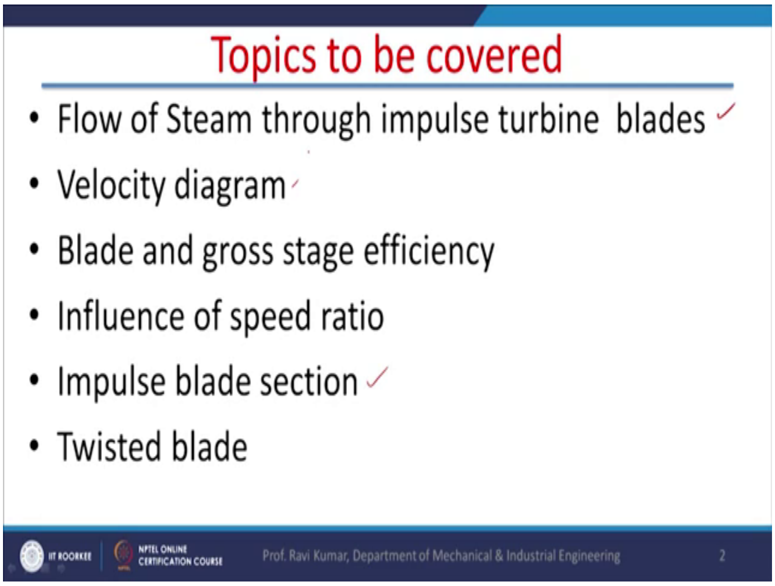

So, today we will cover the flow of steam through impulse turbine blades, as you know there are two types of turbines; impulse turbine and impulse reaction turbine. So, today we will focus on the impulse turbine blades. We will draw a velocity diagram for impulse turbine blades; we will discuss about the blade and gross stage efficiency; influence of a steam ratio on the efficiency of a steam turbine impulse of steam turbine; we will discuss about the impulse blade section and at the last we will discuss a little on twisted blades in the steam turbines.

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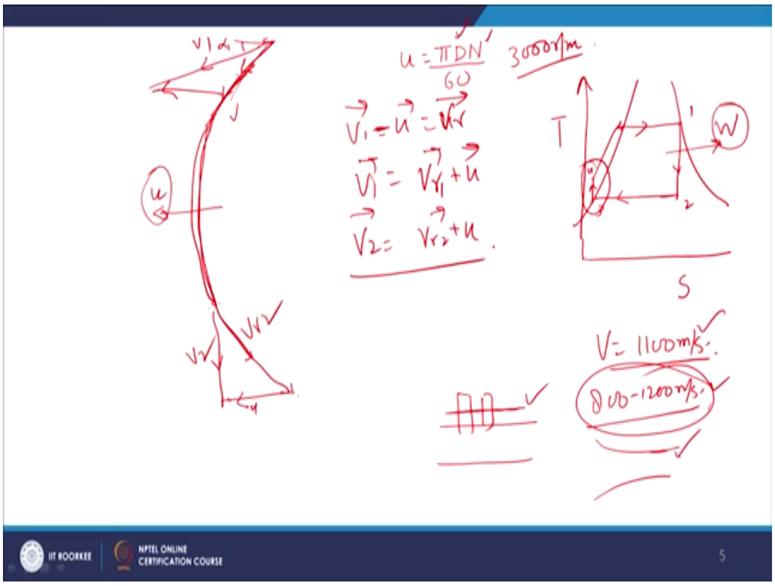

Now, in this steam turbine the power is developed as all of us know and all the thermal power plants they work on Rankine cycle. If you draw the Rankine cycle on the temperature entropy diagram, the ideal Rankine cycle is going to be like this. So, here the expansion of a steam takes place in process 1 to 2 and 2 to 3 the condensation of steam takes place, 3 to 4 pumping or increasing the pressure of the working fluid that is water and 4 to 1 heating in the boiler. So, if the entire cycle we get output only through process 1 to 2, that is the work output; otherwise in process 3 to 4 also there is work interaction, but here work is done on the system.

So, in the entire cycle we get work output from the steam turbine. And, steam turbine as you know normally steam impulse turbine or impulse reaction turbines are used in the power plants. Nowadays the application of impulse reaction turbine is more because they have certain advantages over impulse reaction turbine which I have discussed in the previous lecture.

So, here we will draw the velocity diagram. Velocity diagram is what should be the direction of the velocity so that the steam does not strike the turbine blade because if the steam strike the turbine blade it will damage the turbine blade because the velocity of the steam is approximately 1100 meters per second. Though it is not constant varies from let us say 800 to 1200. It varies from design to design, but it is quite high and this velocity is it is always it is a supersonic velocity.

When we are having a supersonic velocity and this velocity is at in a convert gain divergent nozzle and certain formulas are used that is how we get the velocity at the exit of the nozzle. Now, with such high velocity steam strikes the blade, but steam does not strike the blade it glides over the blade and there is a change in the direction of the motion of this steam. Steam is entering from this side and leaving from the other side night right and blade is not fixed blade is also moving with the certain peripheral velocity.

Since the blade is moving, steam has to glide over the blade so, first of all we have to decide what should be the nozzle angle at for direction the absolute velocity or speed of the steam should come so that it is strikes the blade. So, we will have to draw a relative velocity diagram right. Now, regarding u peripheral velocity of the steam, u is calculated by pi DN by 60; D is the diameter of the drum because all the blades in a turbine they are mounted over a shaft. So, we take the mean diameter and this diameter is used here for fighting the peripheral velocity N is the rpm.

So, normally in a single steam turbine rpm is quite high, but if you take the multi steam turbine rpm is approximately 3000 approximately. So, we can easily get the value of u. Now, steam should glide over the blade as I said earlier. So, we will say that vector V 1 is. So, V 1 minus vector u should be equal to vector V r relative velocity vector right. So, vector V 1 is equal to vector relative velocity vector plus peripheral velocity vector.

So, in this vector if we add this peripheral velocity vector we will get the V 1 vector right and this angle this angle is known as blade inlet angle sorry the nozzle inlet angle and this angle is known as blade inlet angle. Similarly on the exit side when we go to the exit side, this is V r 2, right. This is the relative velocity with which this steam is living the blade. Now, in this case also the V 2 absolute velocity at outlet is equal to this is r 1 V r 2 plus u. But, here also if you add the peripheral velocity we will get the absolute velocity right.

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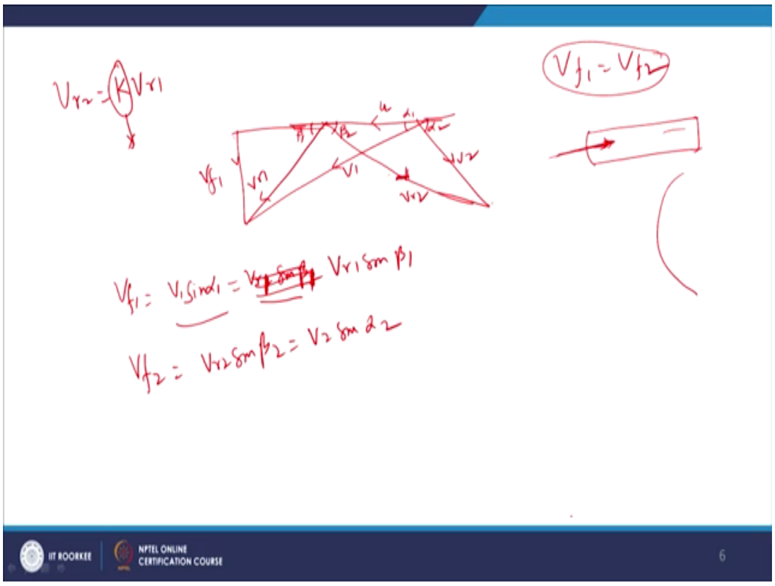

Now, all these two triangles they are transformed on a single base that is u. This is peripheral velocity. This is V r 1 relative velocity. Now, this is going to be the absolute velocity at inlet as you can see here, we have just transformed the vectors. So, we have drawn one vector parallel to this and we have drawn one vector parallels to this from here one vector parallel to this from here and we have simply drawn this triangle.

Now, this is obviously, blade inlet angle which is denoted by beta and this is nozzle inlet angle which is denoted by alpha. Now, if you look at the exit side, the exit side also we have this V r 2 u and then V 2 and for this also we can draw we can draw a triangle like this. This is this is V r 2 and this is V 2. So, V r 2 this is angle known as beta 2 blade outlet angle and this is nozzle outlet angle. The nozzle outlet angle is important in the case when we have to do multi-stage designing of the turbine right; at what angle the steam is coming out of the previous stage and then here it has to be reoriented and then it will go to the next stage ok.

So, now, there is a loss because in ideally there should not be any loss, but there is a loss in the course of travel over the blade surface. So, relative velocity reduces in actual in practice. So, this is known as V r 2 is equal to KV r 1 this is known as blade velocity coefficient K r 2 is known as blade of velocity coefficient. And, this velocity is there is also one of the one velocity factor that is V f 1. This V f 1 is nothing but V 1 sin alpha 1 or we can say V r 2 sin beta 2 both are same V r 2 sin beta 1 sorry now this is not beta 1 or V 1 sorry not V r 2 V r V r 1. So, it is V r 1 sin beta 1. So, this is velocity of flow.

Similarly, on this side exit side we can find the velocity of flow as V f 2 is equal to V r 2 sin beta 2 or V 2 sin alpha 2. Now, this has to remain constant. A good designer should ensure that this component of the velocity remains constant. It means V f 1 should be equal V f 2. If this component is not constant there is going to be axial thirst with the system. Axial thirst means there is the turbine shaft right and there is the thirst in this direction along the axis of the shaft.

When there is a thirst on the axis of the shaft it may damage the turbine, there so many things can happen. In fact, it is going to be accidental if there is a net thirst along the axis of the shaft. So, it has to be avoided at it added should ensure that V f 1 is equal to V f 2. This is only the possible only when this steam glides over the turbine surface.

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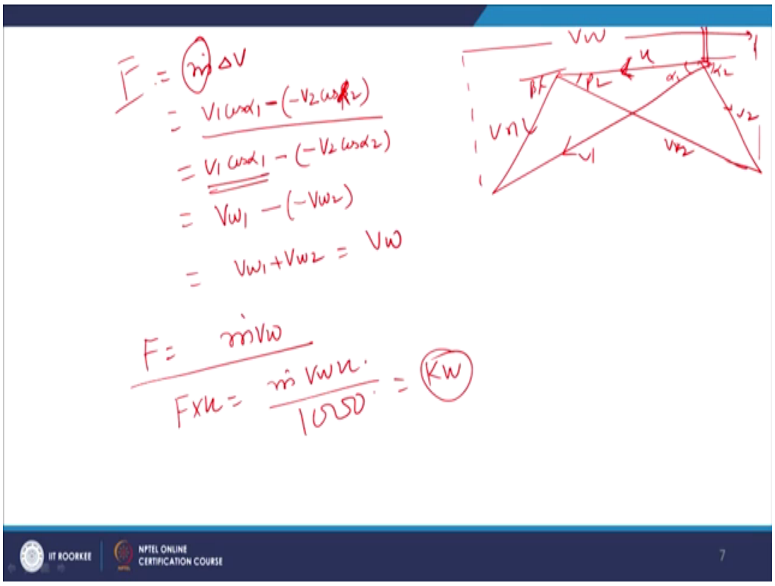

Now, output of the turbine – force, how much force is being exerted? Now, force is change in momentum. Now, if you draw the velocity diagram on this side you will draw the velocity diagram, this is V 1 V r 1 beta 1 beta 2 V 2 sorry V r 2 V 2 and u.

Now, force F; F is change in the velocity this is known as V w wave velocity. Now, F is change in velocity right sorry change in momentum rate of change of momentum not change in velocity rate of change of momentum. So, if we assume that there is a flow of 1 kV per second so, it is going to be change in the velocity, F is equal to m delta V. So, if you assume m is equal to 1 and then it is going to be the change in velocity and which velocity? Velocity which is with component of V 1 which is causing force on the blade. We just causing force in this direction, direction of u of the blade that is V 1 cos alpha 1 that is a component which is causing force in this direction.

Now, in the same direction change in now minus V 2 this is alpha 1 and this is alpha 2. Component of the velocity which is causing force on the blade so, it is going to be minus V 2 cos alpha 2 not beta alpha it is going to be alpha. So it is going to be V 1 cos alpha 1 minus V 2 cos alpha 2, this is alpha 2 right. Now, V 1 cos alpha we can say it is will component of one inlet this is a will component and V 2 cos alpha 2 we can say it is will component of exit. So, it is going to be V w 1 plus V w 2 and that is core known as V w.

Now, if the mass flow rate is m dot. So, definitely the force is going to be m dot V w. The blade is moving with velocity u right so, it is going to be. So, if you want to find output then F into u m dot V w u that is going to be the output of the turbine. Now, with this if you divide this by thousand we are going to get output in kilo watts that is how we can calculate or we can find output of the turbine using the velocity diagram.

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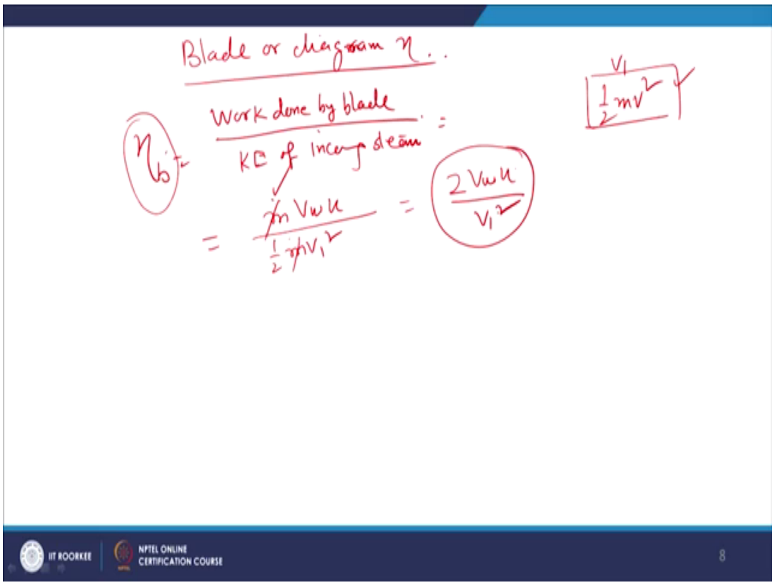

Now, every turbine has certain efficiency every machine has certain efficiency. So, so is the case with the steam turbine also. A steam turbine also certain efficiency and which is known as blade or diagram efficiency blade either we call it blade efficiency or we call it diagram efficiency. Now, blade efficiency is work done by the blade divided by kinetic energy of incoming steam.

Now, what does it mean? It means a team is coming with certain kinetic energy right. An ideal which we should have been ideal turbine ideal machine should have been which we should have trap all the energy of the incoming steam; the steam is coming from a nozzle at a velocity let us say V 1. So, it is going to be the half mV square this is the kinetic energy of the steam which is entering the turbine.

Now, in an ideal turbine all these capacitance is high grade energy. So, convergent of high grade energy to one form to another form is very easy right. So, this kinetic energy should have been completely converted into the work output, then we can say the blade efficiencies is 100 percent, but that does what happen met. I mean 90 percent 80 to 90 percent of this energy is trapped by the turbine but, remaining 10 to 15 percent of 5 percent energy it goes out with the a steam which is giving the blade.

In ideal condition what should happen? It should happen something like this steam is entering the turbine with certain velocity and there is no output velocity still water we are or still steam we are getting outside, then it is 100 percent efficiency, but practically it is not possible. A steam will leave the steam turbine with certain velocity and this out going velocity will reduce the magnitude of the outgoing velocity will reduce the blade velocity blade efficiency.

So, here the formula is simple work done by the blade as we have calculated earlier; work done by the blade is mass flow rate V w and multiplied by u in watts we are not divide unit by 1000 and kinetic energy of incoming steam is half m V 1 is square. So, simply and this m will be canceled out m will be canceled out and then we will get 2V w u by V 1 square. Now, this is blade efficiency and it is independent of the mass flow rate right.

So, it is a function of will component of the velocity diagram, peripheral velocity and velocity of oh sorry the velocity of incoming steam and it is a strong function of velocity of incoming steam. Now, after the blade of diagram efficiency there is another term which is known as gross stage efficiency.

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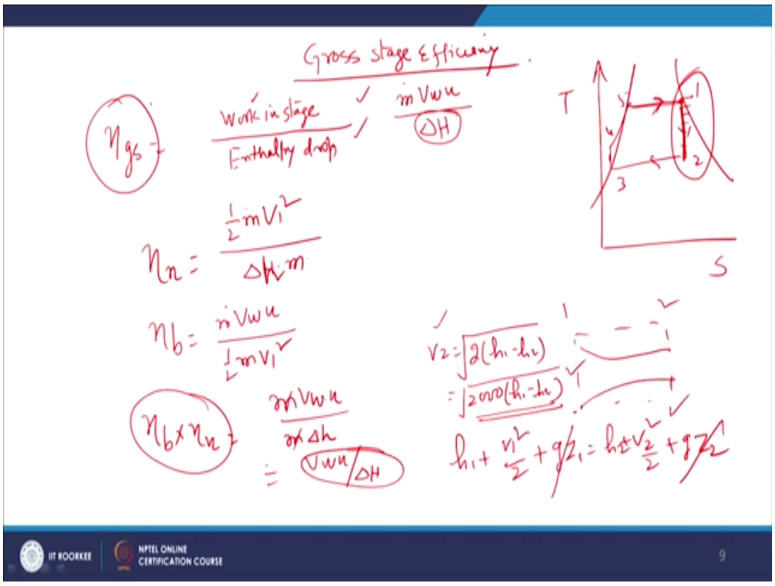

Gross stage efficiency: now, in a steam turbine there number of a the stages. Gross stage efficiency is very important tool while designing is multistage steam turbine right. So, it gives us idea about how much energy is being converted into the useful work in each stage right. So, this is known as gross stage efficiency because during expansion in a turbine, now if you draw the again the Rankine cycle during expansion. So, this expansion is taking place in number of a stages if because in actual practice multi stage turbines are used, single stage turbines turbine is not used.

So, if there is a number of stages so, in each stage some enthalpy drop will be take taking place. So, suppose there is a terry stage turbine. So, in each stage certain amount of enthalpy drop will take place and so, we are concerned with the energy only right now. So, this much of enthalpy drop how much output we are getting that is it.

Now, here we should understand nozzle is also part of the system expansion process because in a Rankine cycle nowhere expansion through the nozzle is shown. So, so whatever happens in the nozzle it is it is a part of the expansion process from stage 1 to stage 2. We are simply feeding high pressure high temperature steam into the turbine and this nozzle, diaphragm, turbine blades they are integral part of this process 1 to 2 right because.

So, here in order to find the gross stage efficiency we write first of all work in this stage that is work output; work output in the stage divided by enthalpy drop in a stage there are two things work output in a stage divided by enthalpy drop in a stage. So, work output in a stage we have already calculated m V w u that is work output in a stage enthalpy drop delta H. This is the grace gross stage efficiency. Now, it can be further modified because this enthalpy drop; basically this enthalpy drop is in nozzles where this enthalpy change in enthalpy is converted into the kinetic energy right.

So, if you look at the nozzle efficiency; efficiency of the nozzle efficiency of the nozzle if you talk about the efficiency of the nozzle it means if efficiency of the nozzle reflects that what is the enthalpy drop with the nozzle and what part of this enthalpy drop is being converted into the kinetic energy because nozzles simply converts because if you look if you consider nozzle as a control volume this is side 1, this is side 2 and if you apply the first law equation h 1 plus V 1 is square by 2 plus g Z 1 is equal to h 2 V plus V 2 square by 2 plus g Z 2. If it is a horizontal nozzle this will be canceled out. V 2 V 1 is V 2 is much higher than V 1 exit velocity is much higher than V 1 inlet velocity.

So, this can also be considered 0 or it is negligible in comparison to V 2. So, V 2 we get is under root 2h 1 minus h 2 and were doing calculation this is a normal mistake by the students they take enthalpy in kilo joules right and then they multiplied difference multiplied by to under root, it should not be like this because velocity is in meter per second. So, if you are taking in enthalpy in joules only then you will get correct answer.

So, enthalpy drop now this enthalpy drop what part of this is being converted into the because nozzle has some internal frictions also, internal losses also. So, what or heat transmission to the surroundings cannot be denied, though it is negligible in case of nozzle that is why we consider flow through nozzle as an adiabatic flow because for a the control volume remains inside the nozzle for very short duration of time ok.

So, the nozzle efficiency we can say that output energy going with the out outgoing steam that is half m V 1 is square that is the steam which is leaving the nozzle divided by enthalpy change delta H right and multiplied by m of course, because this is specific enthalpy. Now, we know that blade efficiency is also something like there V w u m divided by half m V 1 square. Now, if you multiply this blade efficiency by nozzle efficiency, an efficiency of the blade and efficiency of the nozzle, what we are going to get? We are going to get mV w u divided by m delta h this is small h delta h and this m will be cancelled out and we will be getting Vw u by delta h.

So, if you want to have gross stage efficiency then simply we can multiply these two efficiencies we will be getting gross stage efficiency.

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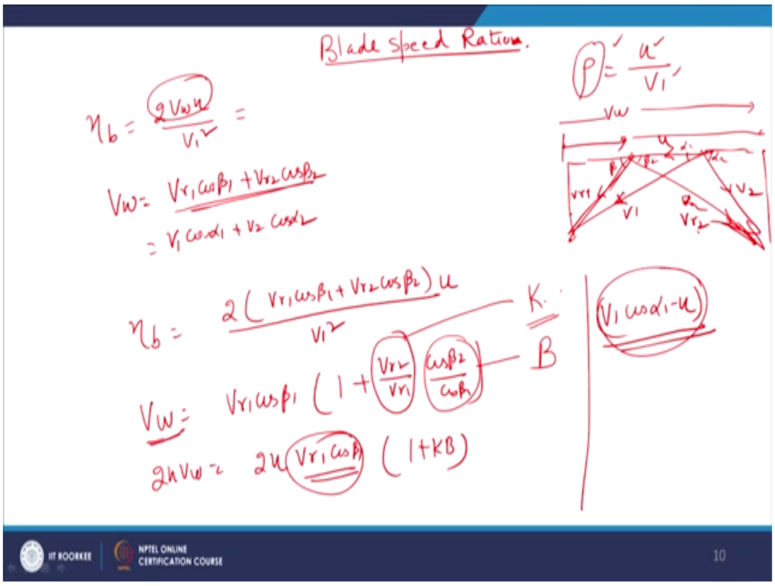

Now, the next thing is influence of blade speed ratio. Blade speed ratio, as we discussed earlier the blade speed ratio is u by V 1 peripheral velocity divided by inlet absolute inlet velocity and it is denoted by rho. If you look at the velocity diagram again this is V 1 V r V r 1 V 2 sorry. This is u V r 2 and this is V 2 right and this is V w this is beta 1, beta 2, alpha 1 and alpha 2. Blade efficiency is 2 Vw u by V 1 is square right.

Now, if we increase how this speed ratio is going to affect the blade efficiency because this speed ratio is also very important parameter while designing a turbine right. So, blade efficiency is V w u by V 1 square, now this can further we modified as because V w is we can always take this is V r 1 cos beta 1, this is V w. So, this is V r 1 cos beta 1, this is V r 2 cos beta 2, this V r 2 V r 2 cos beta 2. So, V w can also be taken as V r 1 cos beta 1 plus V r 2 cos beta 2 and it can also be taken as V 1 as we did earlier V 1 cos alpha 1 plus V 2 cos alpha

2 either way. So, we are considering this. So, if we take this then blade efficiency is going to be equal to 2 times V r 1 cos beta 1 plus V r 2 cos beta 2 divided by V 1 square right .

Now, here V w is as we said V r 1 cos beta 1 plus V r 2 cos beta 2 or we can take V r 1 cos beta 1 plus V r 2 by V r 1 cos beta 2 by right. So, V w is V r 1 cos beta 1 this is the ratio. This we have earlier say this is the velocity ratio it is denoted by K V r 2 V r 1 when there is no friction laws it has to be 1, but it is never 1 it is always practically it is always less than 1 and this is blade ratio cos beta 2 where cos beta 1 is called blade ratio it is denoted by V B.

Now, now this V B is with us now if you take 2uV B 2uV w sorry 2uV w because 2uV w is here. So, for 2uV w we will take 2u V r 1 cos beta 1 1 plus KB. Now, V r 1 cos beta 1; now, V r 1 cos beta 1 is always if you look at this diagram it is going to be V 1 cos alpha 1 minus u right. So, this can be replaced by this expression.

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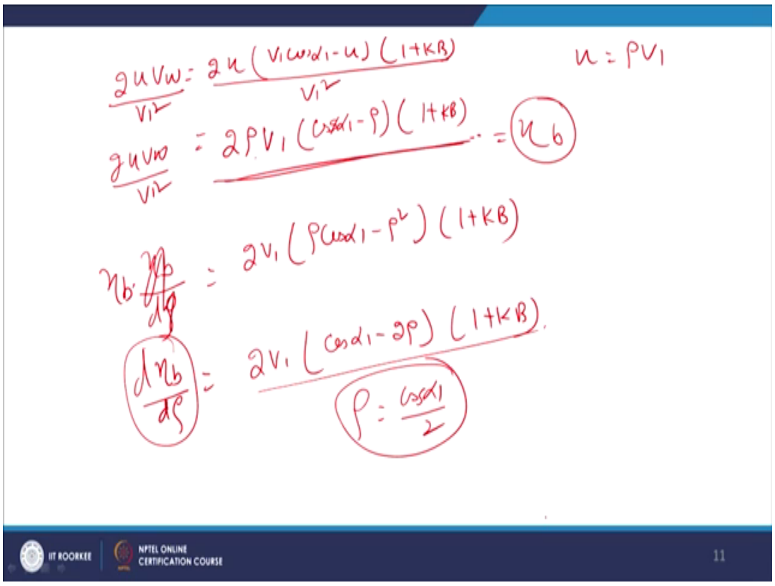

So, the next is going to be 2uV w is going to be equal to 2uV 1 cos alpha 1 minus u 1 plus KB right. Now, we have V 1 here. Now, if you divide this by V 1 square this side also has to be divided by V 1 square and u is equal to also rho V 1. So, V 1 can also with come out from here and we will get 2 rho because this is u is equal to rho V 1, this is also u is equal to rho V 1.

So, we are going to get 2 rho V 1 2 rho V 1 cos alpha 1 minus rho 1 plus KB because u is equal to rho V 1 we are V output here, then V 1 V 1 will be canceled out right and then we will enter in this bracket then it will be this V 1 will cancelled out and the this u by V 1 is going to be the rho. So, this is completely correct 2uV w by V 1 square is this much. Now, this is blade efficiency right.

Now, if you differentiate this blade efficiency with respect to rho 2 V 1 rho cos alpha 1 minus rho square 1 plus KB. Now, this is efficiency. Now, if we differentiate between rho in that case we are going to get 2 V 1 cos alpha 1 minus 2 rho 1 plus KB right. In ideal case K is equal to 1 and since blade angle there is not much in blade angle also beta 1 we can be considered cos beta 1 can also be considered as a cos beta 2.

So, in this case if you want to maximize this value of blade efficiency we can always take rho is equal to cos alpha 1 by 2 to maximize because if you double differentiate this you are going to get the negative value if you differentiated again then you are going to get negative value. So, it means this differentiation you are getting at the maxima and that is rho is equal to cos alpha 1 by 2.

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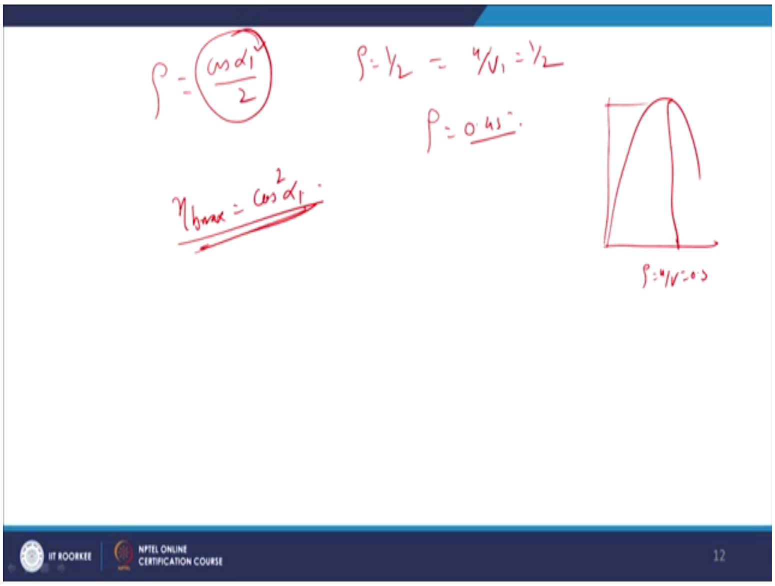

Now, when rho is equal to cos alpha 1 by 2 right it means if the alpha 1 is 0 alpha 1 is 0, then we are getting rho is equal to 1 by 2 is equal to u is by V 1 is equal to half right. If you remember, in the previous lecture we found that at rho u by V is equal to 0.5 maxima efficiency is maximum right, but here it is call cos alpha 1. So, normally while designing steam turbine the value of rho is normally taken as 0.45 not 0.5, it is taken as 0.55.

And, if you put the value of rho here now modified value of rho here in this expression of efficiency you will find the maximum efficiency is cos square alpha 1 right. So, this is the. So, alpha 1 is if it is a 0, then efficiency is 100 percent that is not possible. We do not take alpha 1 is equal to 0 right. So, alpha 1 has to serve as to have certain value and through these certain value we get the maximum blade velocity.

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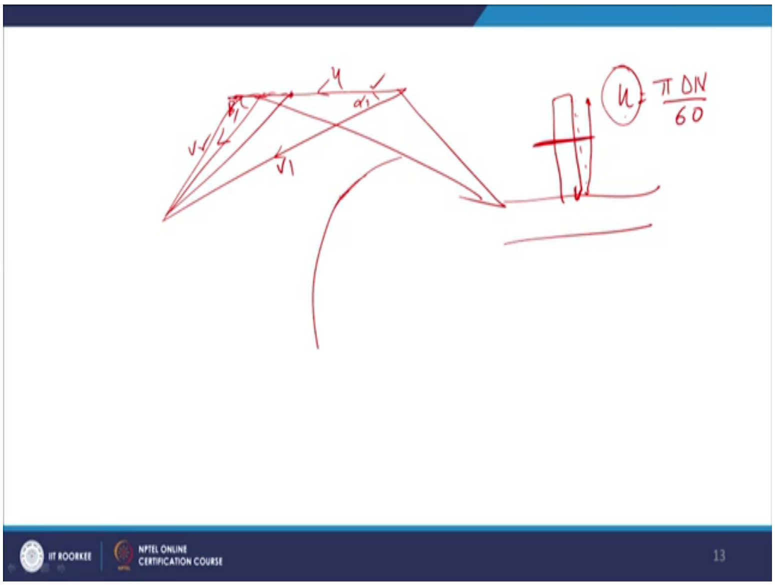

Now, comes the shape of the blade, as I said earlier that we will discuss about the shape of the blade also.

In the steam turbine if there is a drum on the drum a blade is fixed and this blade has certain so, like this profile like this right, but it is not straight it is not a straight the blade is twisted the blade is twisted because what velocity diagram we draw it is taken at the mean diagram. This velocity diagram which we have drawn this u let us take V 1 and V r 1 and this is blade inlet angle this is nozzle inlet this nozzle inlet angle is fixed u is fixed V 1 is fixed.

Now, the beta 1 will change according to the sorry, the u will change according to the position, u is not fixed because u is equal to pi DN by 60. So, this peripheral velocity we will change when we move from this point to this point. In a steam turbine the height of the blade goes up to 1 meter. It is start from 15 to 30 centimeters it goes to 1 and one and half meters.

So, if you are moving in the radial direction the u will change. The moment there is a change in u suppose increases the blade angle will change; if u is reduced the blade angle will also change. So, blade angle will keep on changing right. When you are moving from this side to this side for this reason in a steam turbine when the blades are manufactured they are twisted. So, when you are moving in a radial direction the blade angle will keep on changing in order to ensure that there is no axial shock on a or there is a no shock entry oh sorry, not shock entry no thirst on the blade profile and steam enters the blade profile along to the curvature of the blade. That is all for today.

Thank you very much.