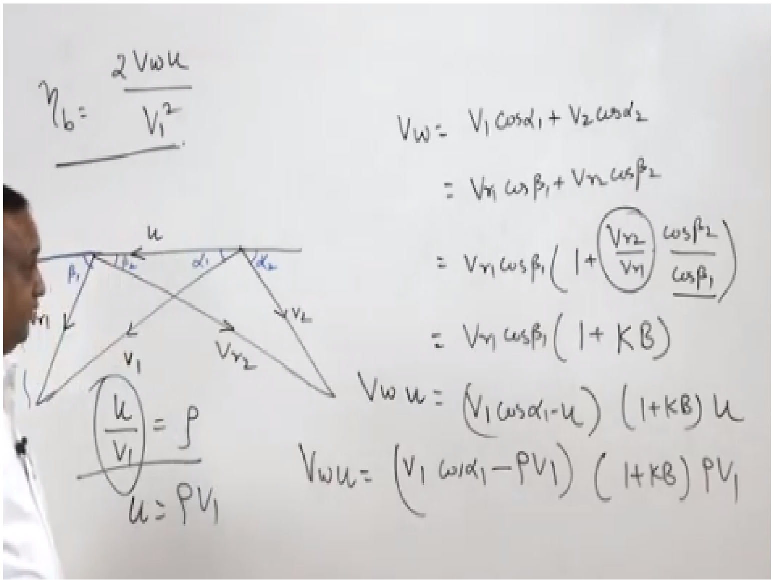
Stream and Gas Power Systems

Prof. Ravi Kumar
Department of Mechanical and Industrial Engineering
Indian Institute of Technology - Roorkee

Module No # 05
Lecture No # 24
Impulse Steam Turbine Performance

I welcome you all in this course on this steam and gas power system. Today we will do the analysis on the steam turbine performance.

(Refer Slide Time: 00:35)



In the previous lecture we have already done the found the blade or diagram efficiency for single stage steam turbine as VU by V1 square VW is the real component of the velocity diagram this is the velocity diagram this is absolute velocity at inlet this is the peripheral velocity of the router this is relative velocity at inlet the relative velocity at outlet and this is absolute velocity at outlet.

And the angles are this is blade inlet angle this is blade outlet angle this is nozzle inlet angle and this is nozzle outlet angle right. And this efficiency has to be maximized because whenever a equipment or system is evolved initially we do not focus on efficiency we focus on the output right when the output then subsequently our focus is shifted on the efficiency that output we are getting at what efficiency.

Because efficiency is a very important parameter to for the performance evaluation of any equipment or any component. So here the blade efficiency the blade or diagram efficiency is expressed by this right. So you will see under what conditions this blade or diagram efficiency is maximum one thing is here that the ratio of U and inlet velocity because this is peripheral velocity this is inlet velocity.

Relative velocity is derived from this and this and all the velocities are derived from this and thus peripheral velocity the main thing is the peripheral velocity and the inlet velocity and there ratio is denoted by row. This blade efficiency will be maximum when this is having the maximum value this is having the minimum value right V1 is let us say it is constant.

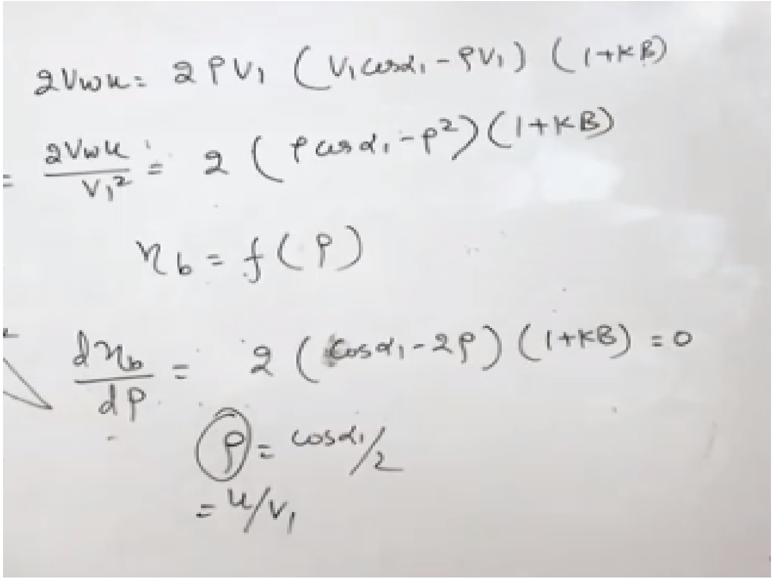
We cannot have V1 minimum is 0 it because when there is no velocity at inlet mathematically then efficiency is going to be the infinite. In this case V1 is also constant will component from is dependent on inlet velocity will component VW is dependent on inlet velocity or relative velocity at inlet either of these and also yet U right. So we will say that VW first of all VW = V1 cos alpha 1 + V2 cos alpha 2.

Right or we can say subsequently VR1 cos beta 1 + VR2 cos beta 2 we will take VR1 cos beta 1 out 1 + VR2 by VR1 cos beta 2 by cos beta 1. Now these values of either there equal beta 1 or beta 2 are equal or their values are very close to each other under any case it is a constant right. And this VR2 by VR1 this is played velocity coefficient right so we can always say that VR1 cos beta 1 = 1 + this is also constant so KB right.

Ideal case K = 1 and B = 1 now VR1 we do not have the value of VR1 because VR1 dependent is dependent on V1 the absolute at inlet. So relative velocity is depended on the absolute velocity so instead of taking VR1 so it cannot be blizzard we will take V1 cos alpha 1 - U. V1 is cos alpha is in this direction that the component of absolute velocity - U will give us the VR1 cos beta1 this component.

So this component of V1 in this direction minus peripheral velocity U will give this component so this is going to be the VW right now U multiplied by U. So this has to be multiplied by U and from here we can take U = row V1. So VW U = V1 cos alpha 1 - row V1 + KB row V1 because U is again replaced by V1 and this U can also be replaced by row V1.

(Refer Slide Time: 06:42)



Now if you further simplify this so 2 VW U is going to be 2 row V1 V1 cos alpha 1 - row V1 + KB now this V1 and V1 this, this and multiplied by this will go here square is going to 2 row cos alpha 1 - row in square 1 + KB is it ok? This row and this row is multiplied V1 is taken out this V1 and V1 are taken out multiplied by this one has gone here row has gone in.

So row cos alpha1 - row is square 1 + KB and this is nothing but blade efficiency. Now we have blade efficiency remember this is a constant this is a constant. Alpha 1 is also constant this is the blade inlet angle and which is constant.

So sorry not blade so nozzle inlet angle it is a constant. So we can say that efficiency of the blade is a function of row earlier lecture we have also discussed then the output when we increase row output increase if you remember that graph. When we increase the value of U by V1 or the row then the efficiency increases and it is the maximum value and then it comes down right. And this sorry not efficiency work output increases and comes down and force decreases.

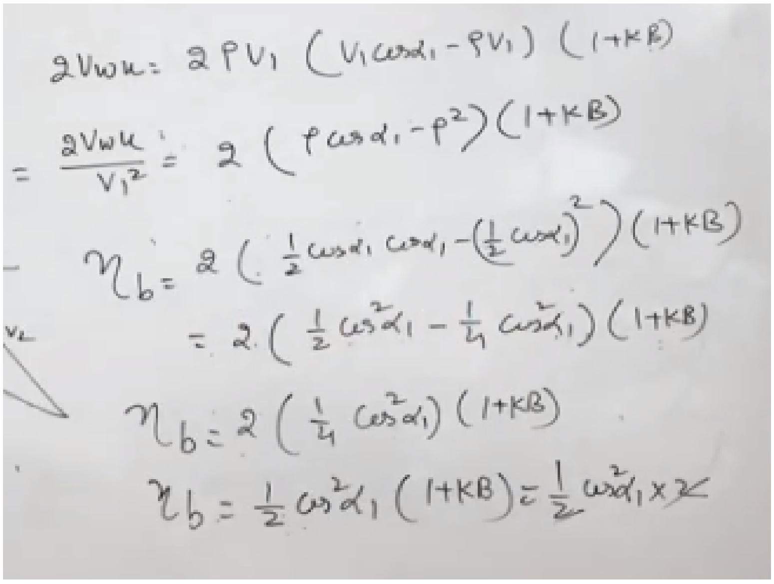
When we increases the value of U by V1 when U = V1 there is no force and when U = 0 force is maximum. So now what we can do we can differentiate this equation for blade efficiency with respect to row.

So what we are going to get two row sorry cos alpha 1 - 2 row 1+ KB right again if we differentiate D square and B by D row square then we are going to get 2 - 2, 1 + KB or = -4, 1

+ KB K and B both are constant so it is going to have negative value. It means if we take this is equal to 0 and the solution will give the maximum value.

Now this is taken as 0 in that case row = cos alpha 1 by so the maximum efficiency or the highest efficiency the value of row has to be half of the cos alpha 1 ok and row is nothing but U upon V1. Now with this value of row what is the value of efficiency? What is going to be the efficiency of the impulse turbine? In order to find that here we will put row = cos alpha 1 by 2.

(Refer Slide Time: 10:29)

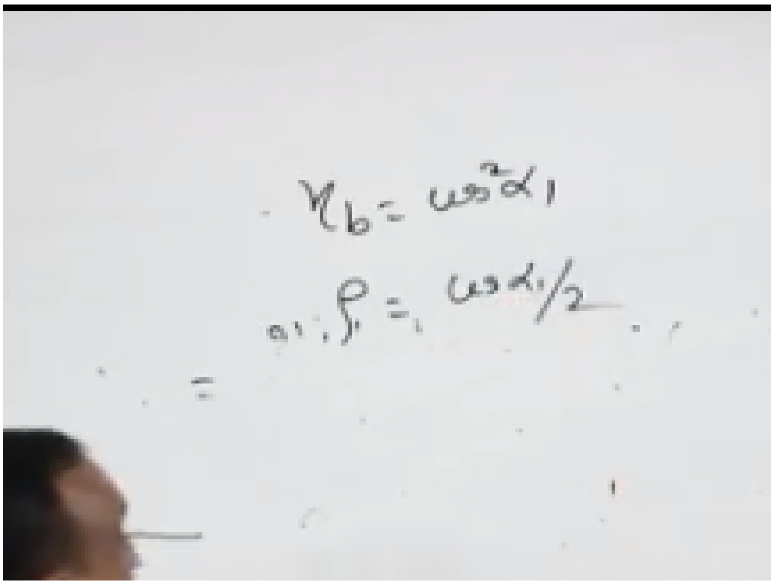


So efficiency of the blade = two times this is half cos alpha 1 cos alpha1 - half cos alpha 1 whole square and then 1 + KB right. And from this you will get two times half cos square alpha 1 – 1 by 4 cos square alpha1 + KB if you further simplify it then you will get blade efficiency as two times 1 by 4 cos is square alpha1 + KB right or efficiency blade efficiency is half cos is square alpha 1 + KB.

Now K is an ideal case relative velocity this K is the ratio of relative velocity of steam which is leaving the blade and relative velocity of the steam which is entering the blade. So this is one if there are no fiction losses B is blade angle normally the blade inlet angle and blade outlet angle the values are very close to each other they are not exactly same they can be exactly same also but in most of the cases they are very close to each other.

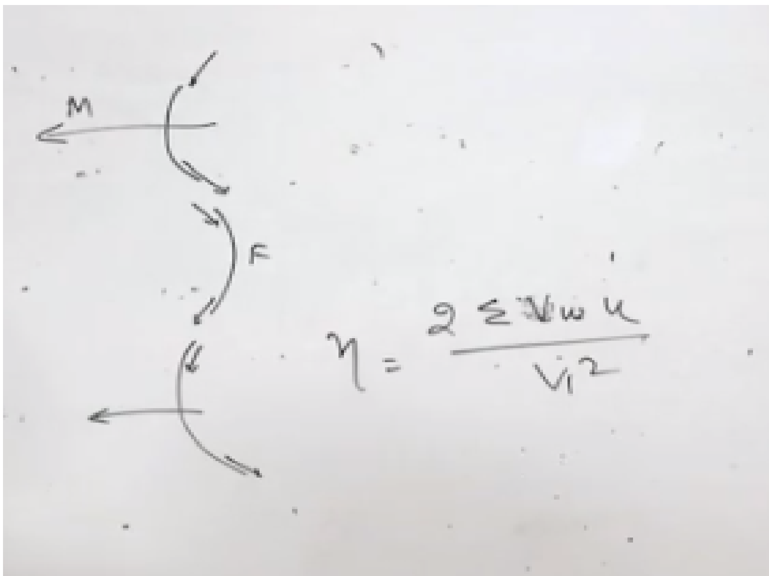
So this K and B we can consider for the sake of convenience we can consider them to be V to be 1. So K is 1, V is 1 + is 2 and then it becomes half cos is square alpha one multiplied by 2 and 2 will be cancelled out.

(Refer Slide Time: 12:35)



We will get blade efficiency as cos square alpha1 right for speed ratio or U by V1 as for a speed ratio row = cos alpha1 right. Now we will talk a little about multi staging what happens in multi-staging? In multi-staging when this is analysis we have done for single staging in multi staging what is done suppose there is a multi-staging velocity component turbine.

(Refer Slide Time: 13:14)

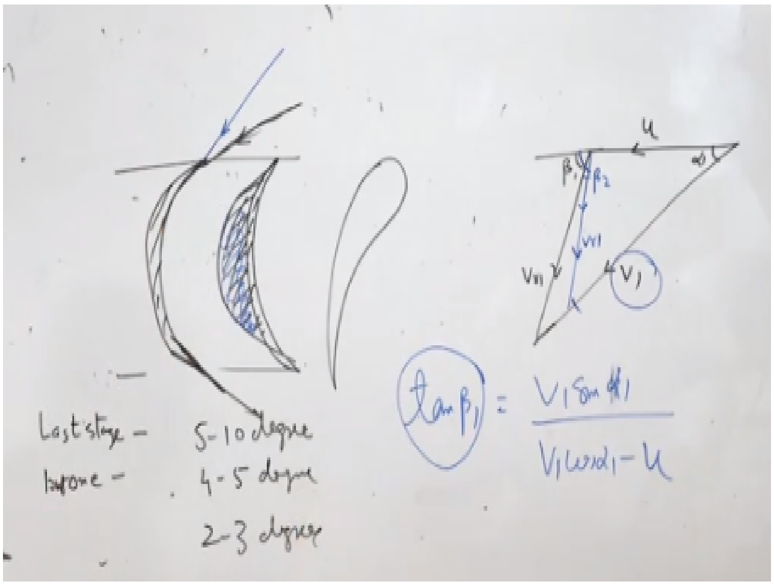


So simply ray diagram if i want to draw this is the moving blade steam is leaving then again there are guide veins steam is entering from here and leaving from here then again though there is a moving blade and there is a fix blade and then again there is a moving blade right. Steam is entering from here and leaving from here and we can have N number of such stages.

And cumulative effect of these stages will be the net output of the turbine or the if we the concerned with efficiency then efficiency is going to be two sigma VW sorry Vw U by V1 square. So this is the sigma will component of each stage will add them and this will give the net output of the multistage in the extremes. Second thing is there are losses for the transmission from this stage to this stage.

The steam leaving the moving blade and entering in the next stage will have some losses in between all these issues will be taking up when we deal with the impulse reaction turbine ok. And after this we will go for selection of blade hmmm angles impulse turbine blade sorry impulse turbine blade sections.

(Refer Slide Time: 15:03)



So for this selection in impulse turbine as you know there are blades made out of plates and there. Co plates like this. So initially this edge was base sharper i will draw bigger diagram i think that will be make things more clear. Initially the blades are like this when it started with the section of the blades of impulse turbine this edge was made sharper.

So that there is a smooth entry of the steam then the steam will glide over the surface and leave from this side later on this side also was made sharper. So the section of the blade became like this so both the ends were sharp and so there are number of plates in turbine there are not a single blade there are number of blades. So what happens steam which is confined to this or which goes into this zone there is a lot of turbines this is a convex surface.

So turbulence takes place and this causes loss or decline in the efficiency of the turbine right in order to overcome this five types of plates were used. So this side what they need the extended side up to this point. So that there was no turbulence in the vicinity of the convex surface and the performance of the blades was improved and you saw the cases this also the exit this was also extended.

So that proper direction is given to this team which is going out of the blade but this profiling of the blade in impulse turbine blades definitely have the improvement in the performance of turbine. In reaction turbines there air fault type of plates these plates will discuss in detail when we will go for the reaction turbines. The choice of plate angles the inlet angle let us talk about inlet angle.

Now for inlet angle as you know that nozzle or nozzle angle is fixed it is outside the turbine this is peripheral velocity of the turbine this is absolute velocity with V is entering the turbine and here is the relative velocity VR1 and this is blade inlet velocity inlet angle. Now the issue is that blade inlet angle is depended on the inlet velocity. Suppose the inlet velocity changes inlet velocity is reduced i want less power inlet velocity is reduced diagram will be modified like this right.

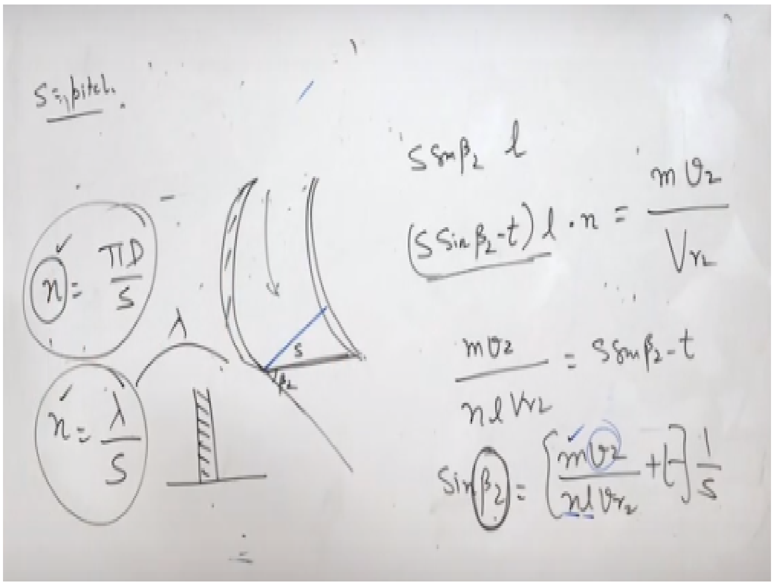
And in that case blade inlet angle will change to beta 2 this is beta 2 right but we cannot say we cannot open a turbine for different loads and change the blade angle. It is not possible at all blades are fixed and they are fixed at a particular angle but when the V1 is reduced. So definitely the blade inlet angle will change and when the blade angle inlet angle is more there will be shock they will be the change in blade angle will call the shock entry in the blade and this may damage the blade also right.

So in at this happens in the case only when then there is a variation in V1. So because 10 beta1 if you want to calculate 10 beta 1 it is going to be V1 sin beta1 sorry alpha1 divided by V1 cos alpha 1 - U right. So normally what we do when there is a partial load the velocity in the last two three stages reduces drastically. So whatever blade angle we calculate with from the velocity diagram in the last stage the blade angle is purposefully increased by 5 to 10 degree.

This is for the design purpose right in last but one is stage the blade angle is reduced by 4 sorry increased by 4 to 5 degree in remaining stages blade angle is increased by 2 to 3 degree. So after all these calculations when we do in the this velocity diagram finally when we go for a design and manufacturing of the turbine so these allowances are taken so whatever value are getting.

So as we are getting 35 initial stage we will take the blade angle 37 or 38 degree so that shock entry is avoided at par root. Now for the outlet of the blade now this is about the inlet for outlet of the blade the different procedure is adopted because the issues related outlet are different.

(Refer Slide Time: 21:21)



Let us take the two blades one is this one another is this one between them there is a space S or the pitch of the blade is S. S is the pitch of the blade outlet angle is beta 2 right and cross section area perpendicular to the flow is this one right or it is S sin beta 2. So S sin beta 2 that is the distance multiplied to the height of the blade will have certain height. So it is S sin beta two multiplied by blade height or length of the blade.

It has got certain thickness here also normally the edges the thickness is 0.001 inch or 0.0254 millimeters there is a blade thickness. So here we will take blade thickness also into the count S sin beta1 - T multiplied by L. So this is the cross section area of these passage perpendicular to the flow right and this multiplied by number of passages N this multiplied by number of passages.

Now how would you get number of passages this is number of passages is N = pie D by S. D is a diameter S is the pitch will get N the number of passages. Suppose there is an arc there is a purpose in impulse turbine it is a partial entry of steam as well in some of the cases in that case suppose if the arc is of lambda.

So N is going to be lambda by S so let us assume there is a entry sorry either of the case whether it is a full entry or partial entry we can have the value of N. So this is the total area is equal to mass flow rate multiplied by specific volume divided by VR2 relative velocity of steam leaving the blades right. Now from here if we resolve this then we will get MV2 by NL Vr 2 = S sin beta 2 - T or sin beta 2 = M V2 divided by M L VR2 + T divided by 1 by sorry S.

So from this we can get the value of angle beta 2 because here we have the mass flow rate which is already with us is specific volume. This we can get from the properties of the vapor then number of nozzles length is say this passage suppose this is perpendicular to this white board and you look at the elevation it is going to be like this right.

So this length of the blade so blade will have certain height or length. So length of the blade is L this is the S sin beta 2 S sin beta 2 - T is in X direction L radial direction that is how we are getting the area multiplied by number of such type of passages. Now from here we will get the blade outlet angle as beta 2. Now here in this case in that inlet for designing purpose we are taking the blade angle larger than the what we have calculated here.

But here in this case the blade angle is taken 2 to 3 degree less than that calculated from this so that i mean in partial load also it works well and further because blade angle is less we will get some reaction also by the changes of velocity of the vapor. So that is why this angle beta 2 is taken normally 2 to 3 degree less then actually which is actually calculated from this formula after this i think we have completed the choice of the bladed that is alpha today.