Steam and Gas Power Systems
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Module No # 05
Lecture No # 23
Impulse Steam Turbine

Hello I welcome you all in this course on steam and gas power systems today. We will start with the analysis will go for the velocity diagram will develop a velocity diagram.

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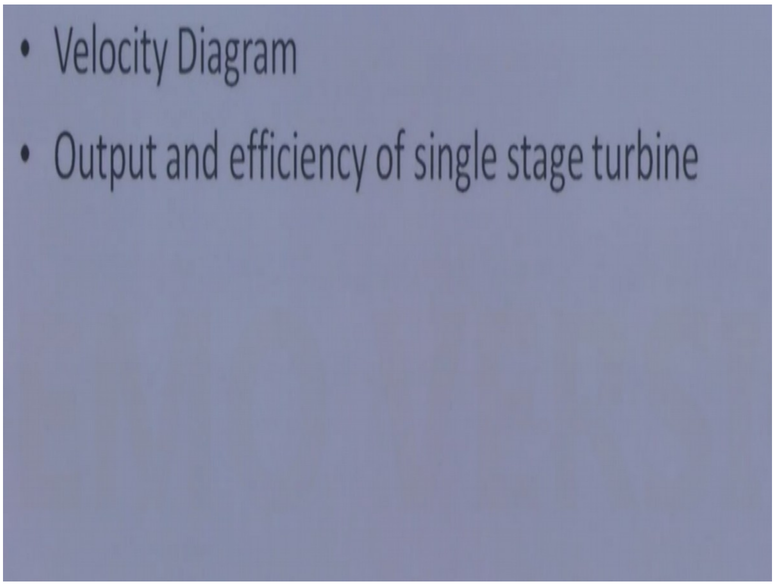

For impulse turbine output and efficiency of single stage turbine and we will try to solve one example also velocity diagram.

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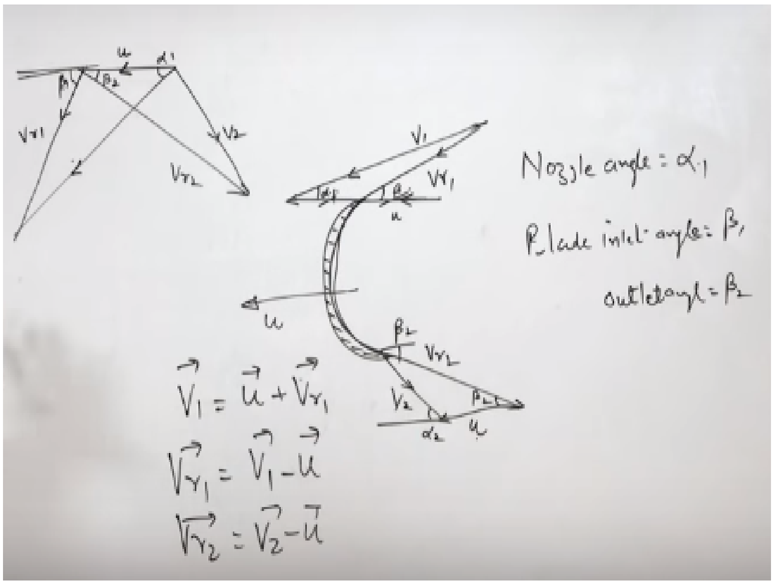

There is a suppose there is blade of an impulse turbine the blade NS i started earlier lecture the steam entering the blade should be such that the angle of entry the steam entering the blade should be such that the steam glides over the blade. Ok and this steam which is coming to the blade will definitely enter at a certain angle right and this angle is known as blade inlet angle right.

For this is the case when the blade is a stationary steam is entering the blade at a certain angle and this angle is known as from this line the (()) (01:34) plate inlet angle. And this velocity is let us say V now moving in a certain velocity U in this direction.

So when the blade is moving in the certain velocity U in this direction then this U means it is like this is also moving in this direction now what is going to happen in that case the net velocity the to which the steam is entering the blade is going to the vector V+ VX is going to be vector U and since it is moving with the certain velocity.

This angle will also change right and this angle will also change and the change angle will be like this right. So we have to keep our nozzle in this direction at alpha not at the direction of alpha blade is moving in this direction and this angle will change to beta relative to the blade. Now we have two types of angle one angle alpha which is absolute another angle beta which is relative to the blade velocity relative to the blade right.

So the nozzle will be in the direction nozzle will be in the direction and since the blade is moving with the velocity certain velocity the steam will enter the blade with relative to this with that angle beta right. So this velocity is known as absolute velocity the absolute velocity and this angle alpha is known as nozzle inlet angle nozzle angle that = alpha 1 let us say this inlet this is alpha 1.

Now this velocity is related to the blade VR1 and this angle beta is blade this beta 1 and vector this will also change. So vector V1 = vector U + vector 1 or blade velocity we can result the absolute velocity VR cannot be measured it has to be determined so will write VR1 vector = vector V1 - vector U right this is about the inlet.

Now the steam is gliding over the surface and leaving with the certain velocity VR2 at an angle beta 2 so blade inlet so blade outlet angle is beta 2. This velocity is VR2 is related to the blade is still moving in this direction with velocity U right. So VR2 is again is going to be V2 U.

So this is going to be the absolute velocity of steam leaving the blade and this absolute velocity of a steam leaving the blade will be at alpha 2 angle this angle is going to be beta this angle and this angle both are same beta 2 right. So this is beta 2 this is alpha 2 V 2 and U now if you transform this angle or these velocities into a single diagram that is going to be the velocity right.

So velocity is common in all the cases this is U this is velocity of the blade right and this velocity V1 this 1 at an angle alpha 1 right and this angle alpha 1 and then this is VR1 and this is beta this is the blade inlet angle this VR1 and blade inlet angle is beta1 this is inlet velocity diagram. Now what we are doing we are just combining these two diagrams in a single diagram for the purpose of analysis that makes analysis easier.

Now regarding VR2 this is going to be the VR2 right and then this angle beta 2. It is going to be the blade outlet angle beta 2 and if you combine this with this one were will be getting V2 so this all these velocities directions of velocities are informed into a single diagram that makes the analysis easier. So this is absolute velocity at inlet this is absolute velocity and this is angle alpha now certain component of these velocity is producing output.

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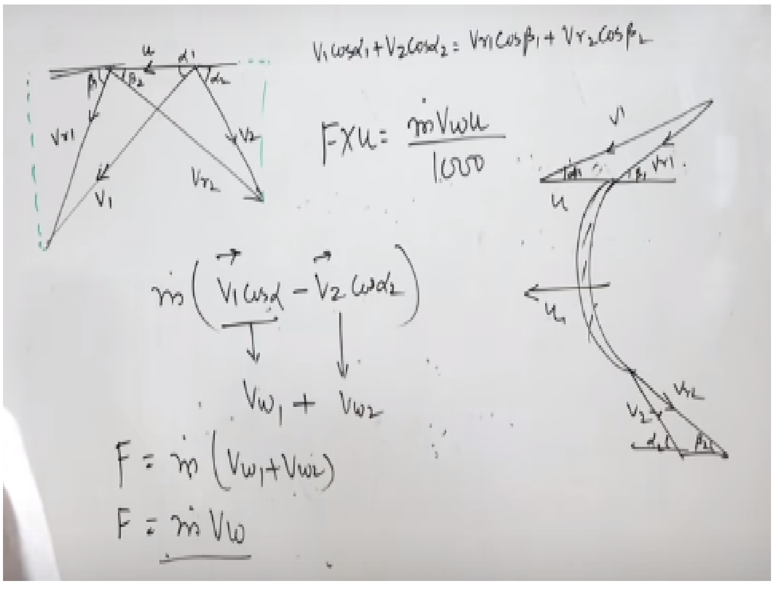

Because this is your channel with this turbine blade channel steam is entering like this blade velocity U in this direction and this is absolute velocity at inlet and this alpha 1 and this is beta one right the component off coming inlet steam component of inlet steam in the direction of the velocity will exert force on the blade right and this is known as will component of steam.

So V1 cos alpha V1 cos alpha right this will be the force or momentum in this direction right. Now again the steam is leaving the blade at the certain velocity now this is alpha2 V2 VR beta2 now component this component which is leaving because the entering momentum minus leaving momentum. So this vector this vector cos alpha two right this will be the force this will be causing the net force multiplied by the mass flow rate.

This will be the net force which is exerted on the blade and which is causing the blade to move ok now this is itself in a negative direction right. So this is known as will component VW and this is VW1 and VW2 and if you take the absolute values will be added because this is also in negative direction right. So the force is going to be the MVW1 + VW2 or mass flow rate VW.

VW is will component V1 cos alpha 1 + V2 cos alpha two but it is interested to see here that will be i mean will be useful later on in the analysis that V1 as alpha V1 cos alpha V1 + V2 cos alpha 2 = VR 1 cos beta 1 + VR2 cos beta 2 there is a benefit of velocity diagram. We can have i mean use the difficulties of involve metry and find some explanation.

So will component can be taken in two ways either we take cos of V1 and V2 or absolute velocity of inlet angle. Cos of inlet angle or an outlet angle or cos. Cos of blade angles and inlet and outlet for relative velocity inlet and relative velocity outlet so this will give us will component mass flow rate and that is the force on the blade the force into velocity will give the power.

So F into VF into U will give the power and that is going to be M dot VW U now this power because power is normally expressed in terms of kilowatt. So divided by 1000 so we can comfortably say that output of a turbine impulse turbine.

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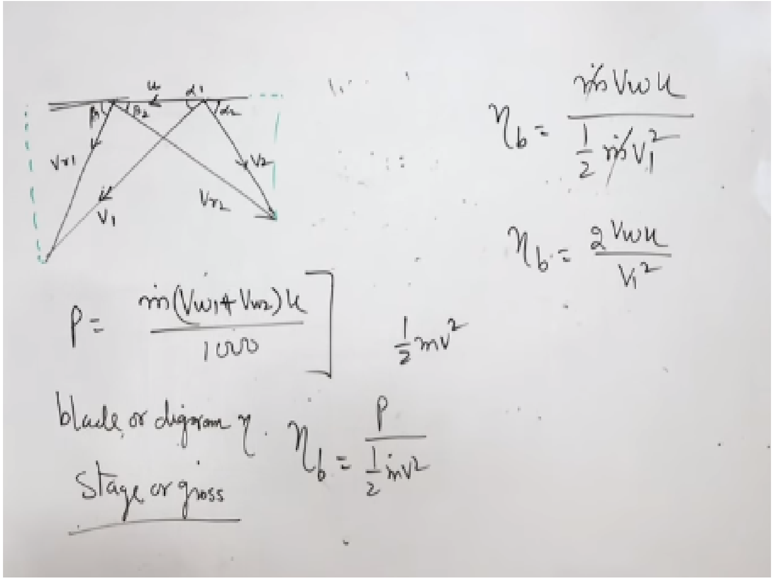

Output power is mass flow rate VW 1 + VW 2 or VW. VW 2 into U by 1000 that is one thing second thing is what is the efficiency of this blade there is a term which is known as blade or diagram efficiency blade or diagram efficiency either it is a blade or some others called blade efficiency or some others called diagram efficiency through this diagram the issue is we are getting this power output from this velocity diagram or the arrangement.

So what is the efficiency of this blade because incoming energy is half Mv square are we able to convert entire energy into the work that we are not doing suppose the energy is going away with the outlet velocity but this much power we are getting to blade efficiency is output divided by half MV square M is mass flow rate. So if we take this into a count then blade or diagram efficiency or impulse turbine is going to be

M dot VW U divided by half MV square or MV square one that is inlet velocity coming with the inlet velocity. So this will be cancelled out so blade efficiency is 2 Vw U by V1 square another term is in this impulse turbine stage efficiency stage or gross efficiency stage means stage is a combination of nozzle in the blade because if we take a turbine stage turbine stage is a combination of nozzle and a blade.

So combined efficiency is going to be enthalpy in the blade it is how much part of the enthalpy in part of the e enthalpy drop in not in the blade in nozzle is converted into the useful work.

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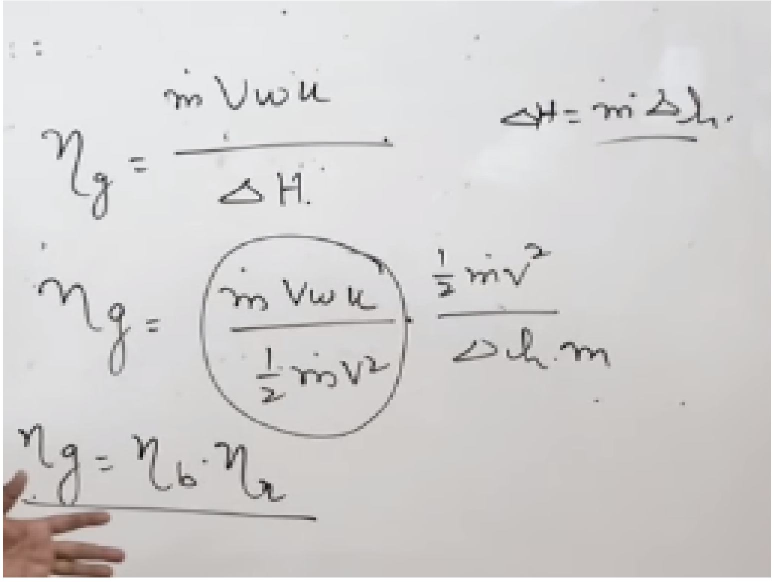

So output so the gross efficiency is going to be the gross efficiency is going to be the output VW U mass flow rate that is output right divided by enthalpy drop in this stage enthalpy drop or this delta H is MH right now this gross efficiency can further be expressed as VW U by half MV square multiplied by half Mv square divided by delta H multiplied by M right now this we have already done this is stage blade efficiency so this is blade efficiency.

So gross efficiency is blade efficiency and this you remember about the nozzle this is the enthalpy drop this is the kinetic energy of the steam which is the nozzle. So this is the efficiency of the nozzle. So stage efficiency is the product of blade efficiency and efficiency of the nozzle. So definitely stage efficiency is less than the blade efficiency if there are no fiction losses in the passage then the relative velocity at the inlet should be relative velocity at outlet.

Because in impulse turbine ok there is the steam is simply gliding on the surface.

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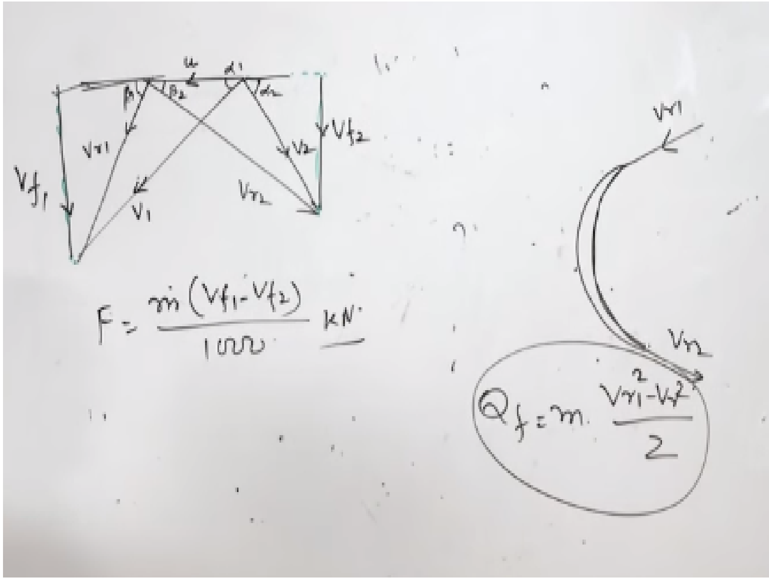

So when the steam is only gliding on the surface then this is VR1 and simply it is gliding on the surface and leaving from this side then VR2. So this velocity should not change so due to the fiction it is a change in this velocity in actual practice and this energy loss in fiction is MVR1 square - VR square divided by 2 this is kinetic energy the kinetic energy based on the relative velocity at inlet minus kinetic energy based on the relative velocity outlet.

We will give the fiction losses in the passage the third thing is this is the component we are getting which is rotating the shaft now this component will cause thirst along the excess of the shaft this is the excess of the shaft. So this is the force we often which is this is the flow velocity of flow this velocity of flow component will cause thirst on the shaft in ideal case this is VF1 and this is VF2 in ideal case VF1 should be equal to Vf two then there is no thirst along the access along the shaft.

If there is of VF1 is not equal to VF2 then there is going to be a thirst along the access of the shaft that is going to be mass flow rate VF1 – VF2 divided by you can say 1000 kilo newtons right now based on these formulas let us do analysis of a impulse turbine the statement of the problem is given here.

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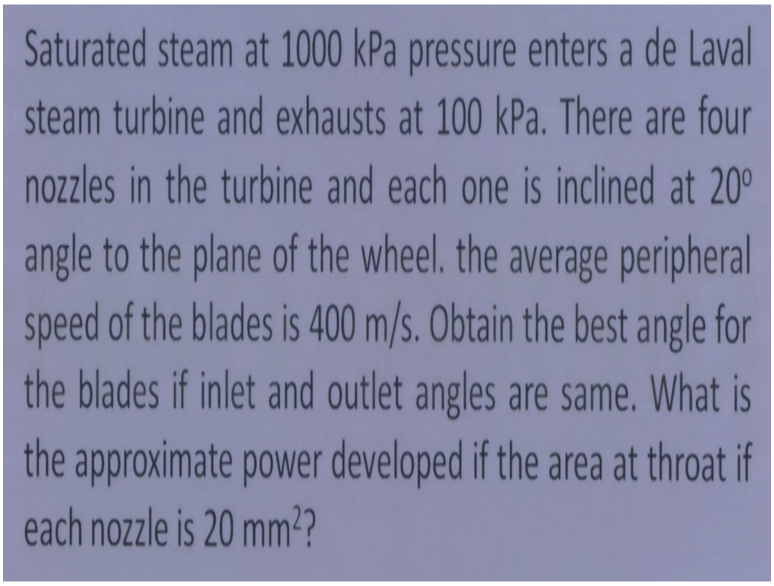

So actually the steam has thousand kilopascal is 10 bar pressure enters a de level steam turbine is a single stage in steam turbine thirsisting of a one row of blades and one row of muscles exhaust is 100 kilo pa. 100 kilo pa is almost atmosphere pressure there are four doses in the turbine and each one is inclined 20 degree ideal to the plane of the wheel the average peripheral speed of the blades is 400 meters per second obtain the best angle for the blades.

If inlet and outlet angles are same what is the approximate power developed if the area at the throat of each nozzle is 20 millimeter in square.

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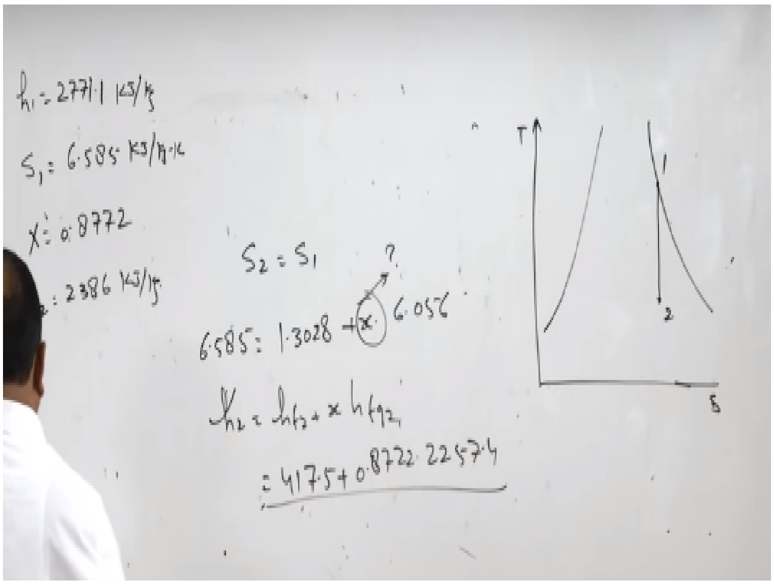

So if first of all we will draw this cycle on a temperature entropy diagram TS we can make use of polio diagram also polio diagram are diagrams are polio diagrams are easy to use or we will start with this one we assume that the steam which is entering the turbine is saturated and it is expended in the turbine state 1 to state 2 now it is expected in the nozzle.

So when the steam is expended in nozzle first of all for the steam, table we will get the value of H1.

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kPa	deg. C	vf	vfg	vg	uf	ufg	ug	hf	hfg	hg	sf	sfg	sg
100	99.606	0.001043	1.692857	1.6939	417.4	2088.2	2505.6	417.5	2257.4	2674.9	1.3028	6.056	7.3588
575	157.17	0.001099	0.327421	0.32852	662.56	1902.84	2565.4	663.19	2091.11	2754.3	1.9142	4.8594	6.7736
600	158.83	0.001101	0.314479	0.31558	669.72	1897.08	2566.8	670.38	2085.72	2756.1	1.9308	4.8284	6.7592
1000	179.88	0.001127	0.193233	0.19436	761.39	1821.31	2582.7	762.52	2014.58	2777.1	2.1381	4.4469	6.585
577.4	157.33	0.001099	0.326179	0.32728	663.2474	1902.3	2565.5	663.9	2090.6	2754.5	1.9158	4.8564	6.7722

So this prefers the steam table and at time bar will get the value of enthalpy 2777.1 H1 = 2777.1 kilo joules per KG S1 will tell take this is entropy so entropy is 56.585 kilo joules per KJ Kelvin. Now again the same thing we will use here S2 = S1 is as entropic process.

So 6.585 is going to be there is 100. So it is going to be under 1.3028 + X into 605. From here we will get the value of X right the value of X is so X the quality of steam or X is 0.8772.

Now once we have the quality at state 2 we can find enthalpy at stage 2 also S2 = HF2 + XHFG 2 that is 417.4 + 0.8722 into 2257.4 and this will give us enthalpy at state 2 as 2386 kilo joules per Kg.

Such step of exercises we have already done right now X2 - X1, X1 - X2 here X1 – X2 if you have the value of H1 - H2 we can find the velocity of exit steam right.

So velocity of exit steam is going to be 2 into 1000 H1 2777.1 - 2386 have begin 1000 because this is 1 kilo joule this is a normal mistake which is written by the students they do not multiply this by 1000 so V = 884.4 meters per second or we can say this is V1 this is the velocity of turbine blade this is inlet velocity of turbine with V1.

So V1 is 884.4 meters per second right now this thing if you look at the Moliere diagram this is enthalpy and entropy diagram.

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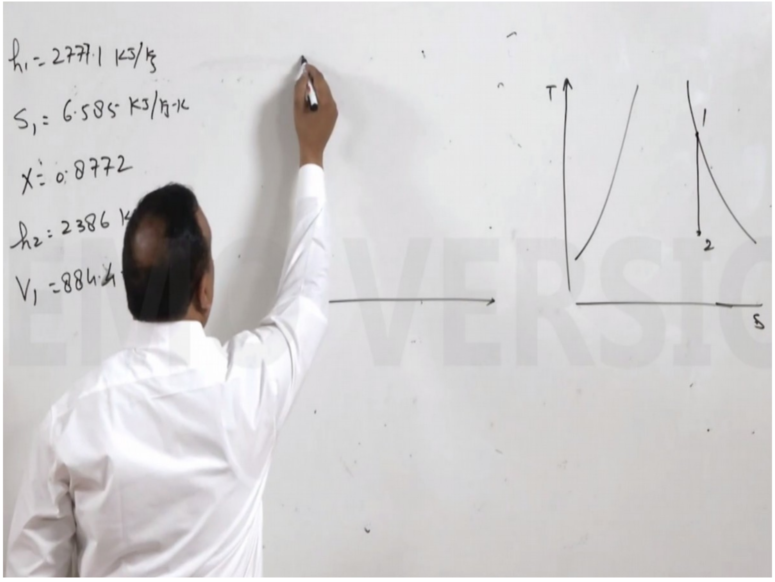

Let us look at the Moliere diagram which is enthalpy entropy diagram HS this is a saturation line X = 0 right and if you take the constant pressure lines also if you take this ten bar the line or thousand Kpa or one mega pastel line right draw a vertical line which is constant entropy diagram and where it cuts the 100 Kpa line that is the state to this is state1 and in this diagram there are constant quality lines also sorry this is X = 1.

So constant quality lines also so X = 0.9, 0.8, 0.7 something like that so from this diagram you can immediately find H1 - H2 there is a benefit of Moliere diagram immediately you can find H1 is H2 and quality of team as well anyway we have the inlet velocity of a steam in the steam turbine peripheral velocity of a steam turbine is 400 meters per second if you look at the statement peripheral velocity is 400 meters per second. So 400 meters per second

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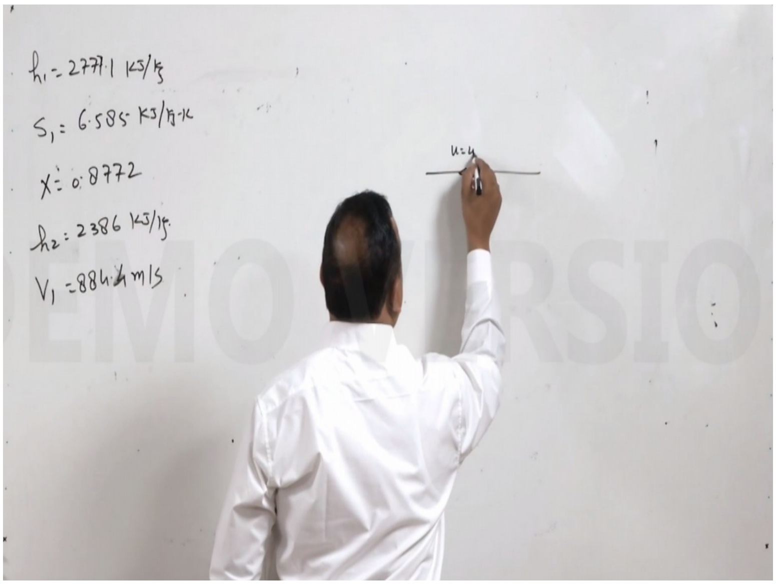

Is peripheral velocity right inlet velocity is weight 844 meters per second this angle inlet angle is given here each one is inclined at sorry 20 degree angle right so inlet angle is given. Now we can easily make the triangle i mean using the skills of trigonometry we can find the value of VR1 we have several ways of doing it you take X component and Y component right and you square them and add them or we can find the value of tan beta 1 = 884.4.

Sin 20 right divided by 884.4 cos 20 - 400 this will give the value of beta 1 S 35 degree one we have the geometrically. It can also be done analytically it can also be done so just draw from here line at 35 degree and when it is cutting there this will give the VR1. So all problems related with the velocity diagram can be done geometrically and trigonometrically.

So this gives the value of beta 2 also S under the beta 2 also beta two also is 35 degree this is also 35 degree because it is given here inlet and outlet angles are same so beta 2 we have taken 35 degree relative velocity vr one VR1 is 526.6 meters per second just under take a root of this and a square of this will give the VR1 now because losses are not mention.

So we can assume that VR2 also = 526.6 metre per second because there is no change in the relative velocity in impulse turbine now we want to find power developed in order to have power developed we should have will component.

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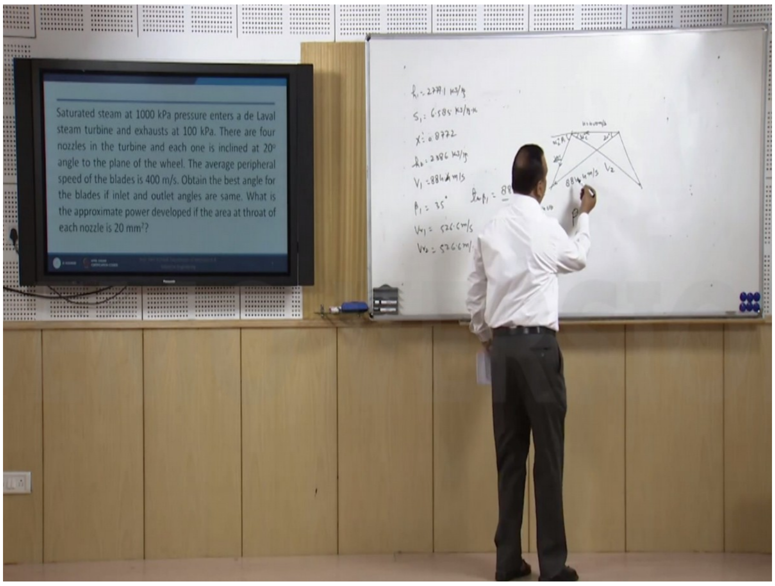

So power developed is going to be power is going to be because we do not have the value of V2 though we can calculate but there is no need we will take VR1 cos beta 1 + VR2 cos beta two that is the same thing so it is going to be VR1 cos beta 1 + VR2 cos beta 2 but here beta 1 = beta 2 VR1 = VR2. So we can comfortably take 2 into 2526.6 cos 35 into cos 35 and it is going to be 862.7 meters per second.

So vw will component is 862.7 meters per second now we can find we have all the required formation to find the blade or the diagram efficiency.

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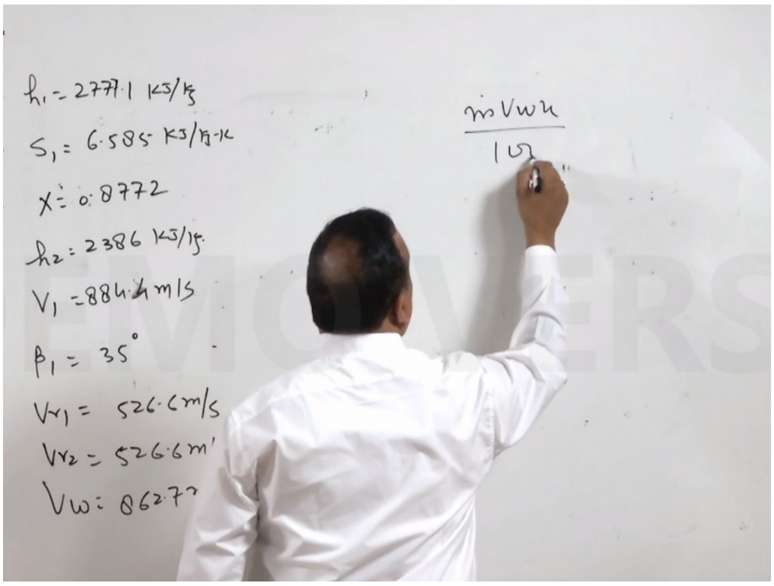

So blade or diagram efficiency can be so power can also be calculated mass flow rate VW U by 1000 we do not have mass flow rate we have VW we have U we have 1000 but blade efficiency can be calculated 2 VW U by V1 square we have the value of VW. We have the value of U and we have the value of V12 into 832.7 into 400 divided by V1 884.4 square and this is 0.88 approximately.

88 % so blade efficiency is 88 % but we do not have mass flow rate once we do not have mass flow rate we cannot calculate how much power has been developed now in order to find mass flow rate let us do one thing because here the velocity is 884 right the velocity pressure ratio at the (()) (29:39) because there is a nozzle the nozzle it is written here about the nozzle no let us take pressure ratio P2 by P1.

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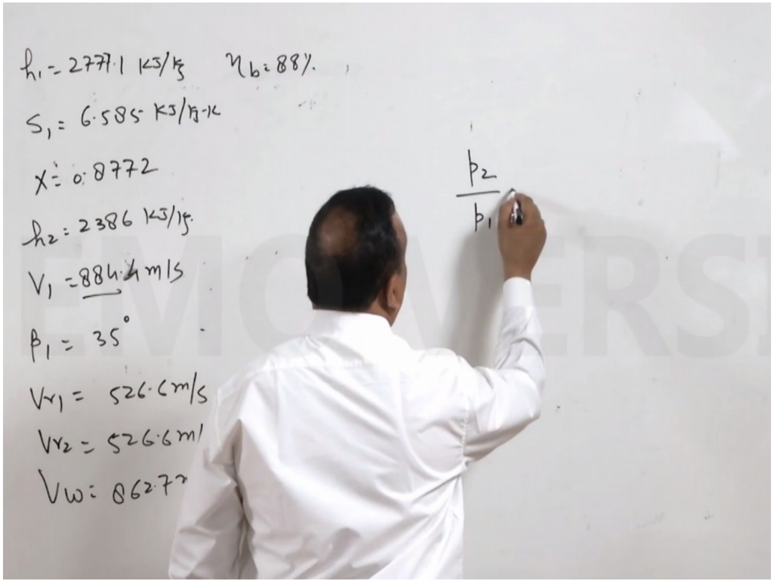

Or P2 by P1 is critical pressure ratio for steam expansion of a steam and that is = 2 by N + 1 is to power N by N - 1 = 0.577 right for a steam value is taken as 1.3 ok in that case we will get P2 = 577.4 kilo pa because P1 is 1000. So this is 5574 exit pressure is 100 kilo pa square it means it is a (()) (30:28) right.

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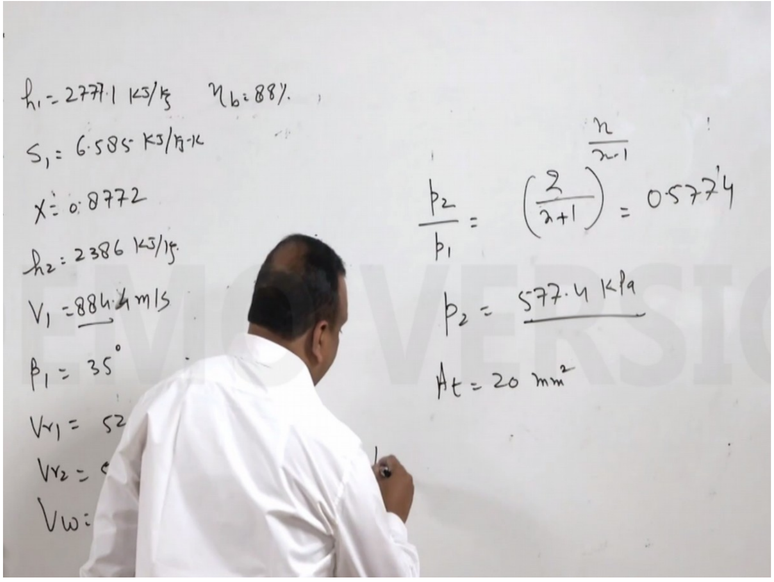

Now we have pressure here we have to find because here the area at the thought is given area at thought is given 20 how much 20 millimetre in square right velocity at a thought area at the thought mass flow rate. So area at the thought velocity at the thought is equal to mass flow rate and spacing volume at the thought from here we can find the mass flow rate right area of the thought is given now velocity at thought now again we will take enthalpy area the expansion is taking place 1 to 2 this is 2.

So this is three so thought is somewhere here two right now we have to find enthalpy at state 2 if you want to use the steam table the steam table can be used if somebody wants to use Moliere chart can be used now enthalpy at state 2 we will have to because pressure is 577.4. So interpolation has to be done data have done here i have found the properties of saturated steam at 577.4 kilo pas pressure.

All the values because these values are not given in steam table so one has to do calculations and find these values from the steam table now once we have the values for 577.4. Now we can find the value of H1 – H2 and using this values H1 – H2 we can find definitely find the velocity of steam and the thought.

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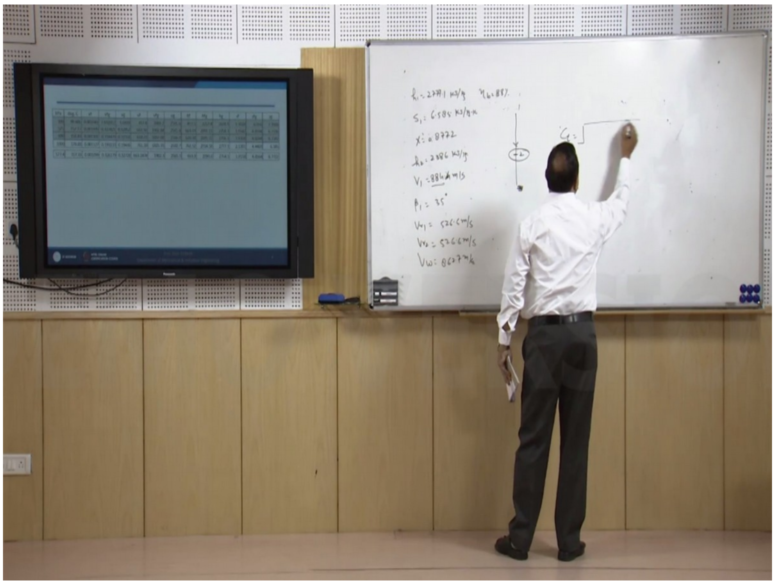

So the velocity of steam and the thought will be again velocity of the steam and the thought is going to be 2 into 1000 H1 – H2 right here this will give the velocity of the thought 456.3 meters per second quality of the steam and the thought now after quality of a steam can easily be calculated thus taking the outstand and entropy process as we did previously quality of the steam of the thought will be calculated and quality of the steam.

Once the quality of the steam is calculated will find the specific volume of the steam and the thought right now specific volume is known velocity is known area is known we can find the mass flow rate mass flow rate is area into velocity divided by specific volume at the thought and this will give the mass flow rate and the of the steam and thought from one nozzle how many nozzles are there are four nozzles.

So this mass flow rate will be multiplied by four we will get the mass flow rate once we have the mass flow rate with us right then we can find the power because power is mass flow rate into W into U divided by 1000 VW we have already calculated peripheral velocity is with us mass flow rate. We have we will be calculating adopting this process divided by 1000 will give the output right that is all over for today thank you very much.