Power Plant Engineering
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Lecture - 16
Impulse-reaction Steam Turbines

Hello, I welcome you all in this course on Power Plant Engineering, today we will discuss about the Impulse-reaction Steam Turbines. Impulse reaction steam turbines are normally used; nowadays that they are normally used many of the steam power plants due to their inherent advantage over the impulse pure impulse turbine. So, today the topics to be covered are the working principle of a impulse reaction turbine.

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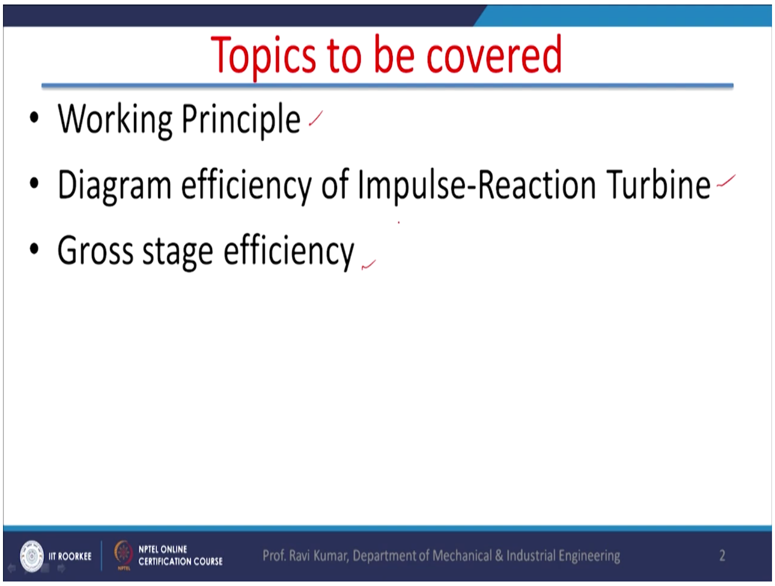

We will discuss about again the diagram and the efficiency of impulse reaction turbine and gross stage efficiency of impulse reaction turbine. So, the impulse reaction turbine as I mentioned earlier also; the pressure drop takes place not only in nozzle, but also during the blade passage when the steam is moving in the blade.

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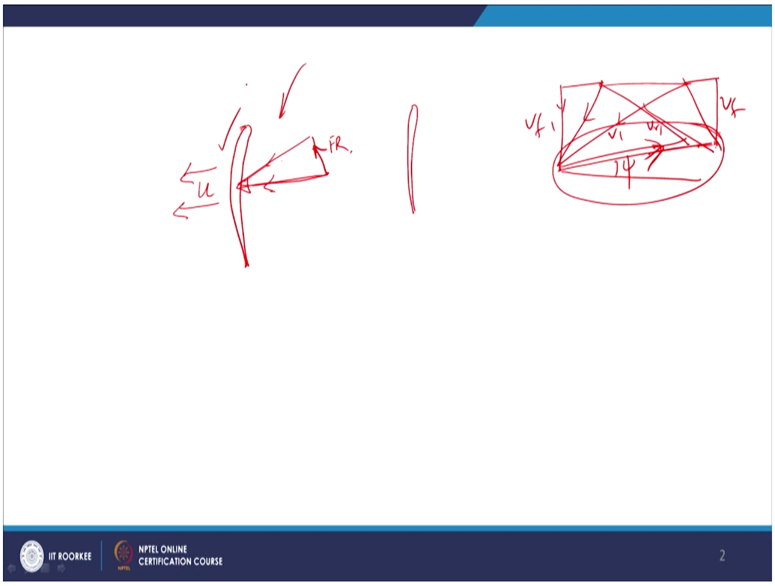

So, when steam is moving in the blade, blades are airfoil in shape for steam turbines and the blade cross section does not remain constant, in impulse turbine the blade cross section. So, sorry not blade cross section, but the space inter blade space right, the blade passage not blade cross section, but the blade passage remains constant right because there is no pressure drop, because here the pressure drop there is a change in the blade passage.

Due to blade pressure drop one force is of obviously, works there is a well component in the direction of u that is one force which works due to impulse action, due to impulse action on the turbine where it is impulse action is same in both the turbines. But, here in addition to the impulse action there is a reaction also, the force due to reaction suppose steam is moving over the blades due to reaction there is a reaction force.

There is the well component of the velocity as you know which exerts force in direction of u, there is the peripheral velocity direction. Now, if you add these two vectors then you will get the final force which is working on the blade, the final force which is. So, final force is not in the same direction as the well force right. Now, this force, this force and the force due to change in axial velocity; suppose in a velocity diagram there is a change in axial, velocity in axial direction. This is V 1 this is V r 1 and this is a change in the velocity in axial direction.

So, V f 1, V f 2 this is psi. So, net force which is working under this plus this force will be the gross force which is working on the blade. So, we will now right now we will neglect this. So, net force which is working on the blade is the sub of the impulse force and the reaction force right. Now, the term comes the degree of reaction into the picture, next it will take degree of reaction.

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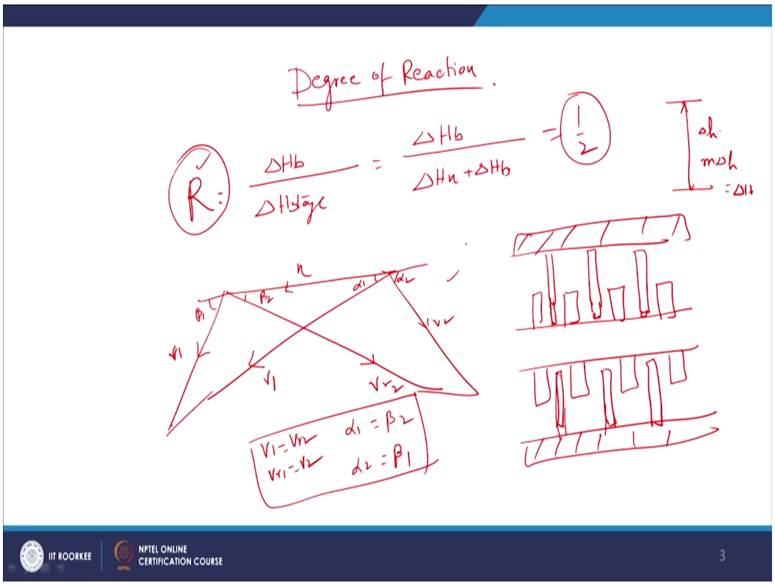

Now, what is the degree of reaction? So, first of all while designing a turbine we take certain we assume or we consider certain enthalpy drop delta h per unit mass or m delta h is equal to gross enthalpy change right. So, this enthalpy change. What part of this enthalpy change is taking place in the nozzle? What part of this enthalpy change is taking place in the passage? That decides the degree of reaction. So, delta H in the blades, delta H total in the stage or we can say enthalpy change in the blades divided by enthalpy change in the nozzle plus the enthalpy change in the blades. This is known as degree of reaction.

Degree of reaction is high it means the enthalpy change in the blades is high, there is a Parson's turbine and in the Parson's turbine degree of reaction is half. So, half of the enthalpy drops with the blades and half of the enthalpy drops in the nozzles and in regarding nozzles they are fixed blades which work as a nozzle. So, in a Parson turbine there are moving blades which are fixed on the turbine surface right and there are fixed blades also.

Now, these fixed blades are not fixed on the shaft, they are fixed on the housing. So, they remain fixed and this combination of one fixed and one moving blade makes one stage in the turbine. So, these blades are fixed and they are extended up to the end of the shaft where they are very close to the shaft, though leakage also takes place between the space between the shaft and the blade edge. But, we try to keep this gap as low as possible; designer they try to keep this gap as low as possible.

This is the I am just explaining the structure of a impulse reaction turbine or parson turbine in particular. So, reaction value of R for Parson turbine is half. It means when we draw the this velocity diagram for Parson turbine V 1, V r 1, beta 1, u V r 2, V 2, alpha 1, alpha 2. So, when we draw the Parson turbine because degree of reaction is half then V 1 is equal to V r 2, V r 1 is equal to V 2, alpha 1 is equal to beta 2 and alpha 2 is equal to beta 1. So, these are the salient features of a Parson turbine which is normally used in power plants and it is a impulse reaction turbine.

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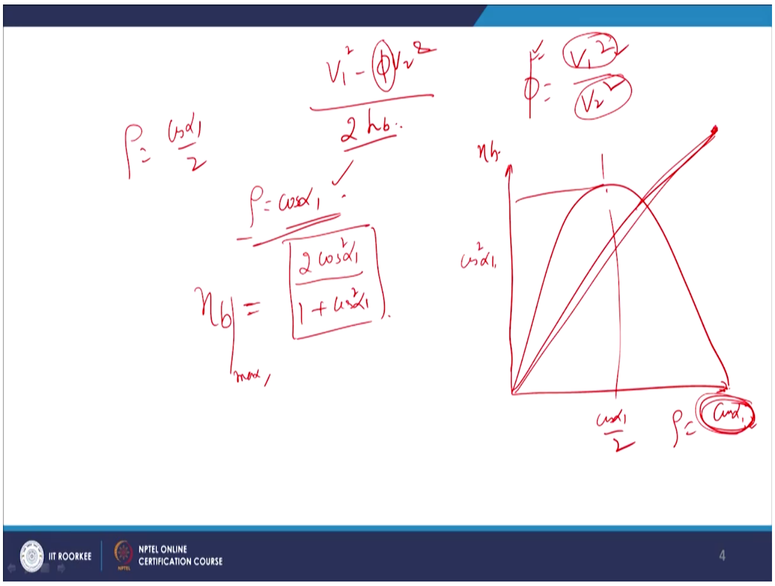

So, efficiency of the fixed blade when they are considered as a nozzle; efficiency of the fixed blade when they are considered as a nozzle is going to be V 1 square minus phi V 2 square divided by 2 h the blade, phi is carry over coefficient phi. Suppose because now what is happening fixed blade the steam is coming out with certain kinetic energy, but when it is entering the moving blade some losses are there.

Now, in account to though in take into account those losses; the carry over coefficient phi is established that is equal to V 1 square by V 2 square. That V 1 square means the steam which is entering the stage, V 2 square is the steam which is leaving the previous stage not this one stage. So, kinetic energy of that steam which is giving the previous stage and kinetic energy of the steam which is entering the subsequent stage that is known as carry over coefficient.

And, it is very important phenomena, very important parameter in designing a impulsive reaction turbine. Now, I will not go for the derivation because the power plant engineering course, I will not go for the derivation for impulse I have already done for impulse turbine. For impulse reaction turbine blade optimum speed is rho is equal to cos alpha 1, if you remember in the impulse turbine rho was cos alpha 1 by 2.

Now, here is the rho is the cos alpha 1 and blade makes you a maximum blade efficiency is a maximum that is maximum is equal to 2 cos square alpha 1 divided by 1 plus cos square alpha 1. That is the value of gross stage sorry the blade efficiency, in impulse turbine it was cos square alpha 1, but here it is 2 times cos square alpha 1 and 1 plus cos square alpha 1. So, definitely the blade efficiencies more if alpha 1 is same, the blade efficiency is appears to be more in case of impulse reaction turbine.

Now, if you draw the curve for this for the sake of comparison between impulse and impulse reaction turbine, if you draw a curve this is cos square alpha 1 and efficiency blade efficiency. So, blade efficiency is maxima, this is cos alpha 1 by 2 blade efficiency is maximum, but here the blade efficiency is going to be like this and it is for the velocity ratio cos alpha 1 only right.

So, we have to maintain the cos alpha 1 as the cos alpha 1, cos alpha 1 if you take the rho is equal to cos alpha 1 in that case the efficiency of the blade efficiency is maximum and it is higher than the efficiency of impulse reaction turbine for same value of alpha 1. There are so many other parameters also I mean to decide the overall efficiency, but this is one of the major parameter for design deciding the blade efficiency; now gross stage efficiency.

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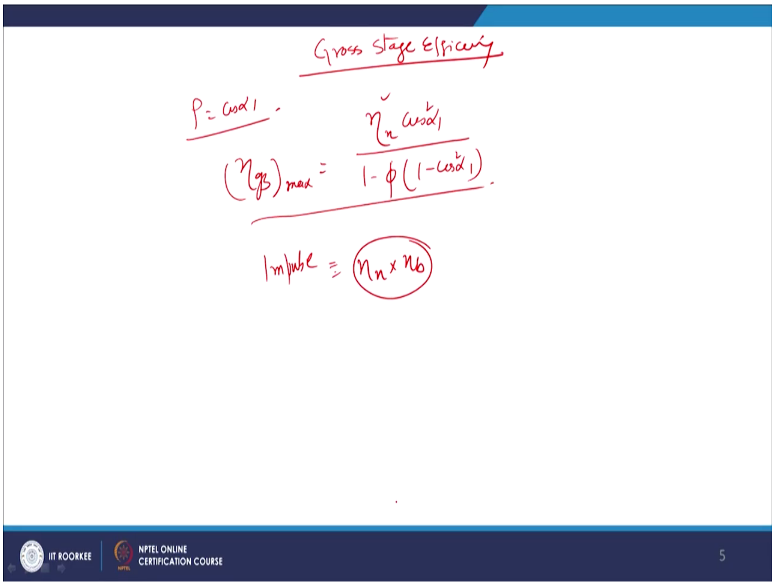

Now, gross stage efficiency if we rho is equal to cos alpha 1 if we take, then gross stage efficiency of; maximum gross stage efficiency of a impulse reaction turbine is efficiency of the nozzle cos square alpha 1 divided by 1 minus phi 1 minus cos square alpha 1.

Now, phi is a carryover efficient I explained you earlier which is not there in a impulse turbine and efficiency of the nozzle right. Gross stage efficiency of this impulse turbine was simply efficiency of the nozzle multiplied by a blade efficiency right. But, here the situation is different and this is the expression for gross stage efficiency of a impulse reaction turbine.

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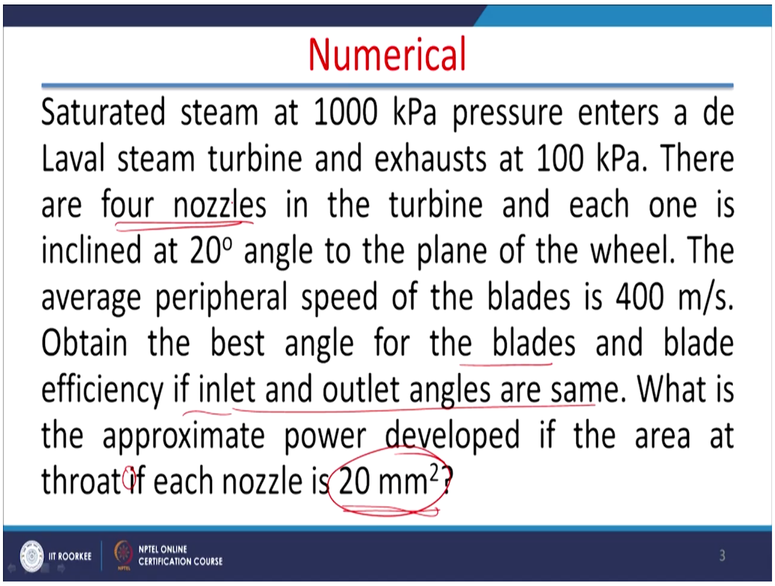

Now, I would like to go for a numerical on impulse turbine, then I will discuss in a very because numericals in power plant are not there to just to check your computational skill; the numericals are solved in the power plant just to have physical ideas of the values. For example: the nozzle angle is approximately 15 to 20 degree, you will get certain ideas about the velocities and the angles.

So, in normally in the power plant we give numericals just to give you the physical idea of the quantities right. So, you may not later on you may not land up with some absurd value say diameter of the rotor is 50 meters, rotor diameter cannot be 50 meters; rotor diameter is a maximum is 1 meter right or blade height is 3 millimeter, blade height cannot be 3 millimeter, it varies between 30 centimeter as I said told you earlier.

So, these numericals are given. So, in the back of the mind you retain that these are the; these are the values which are close to the actual values right. So, we will start with the this numerical on impulse turbine that is saturated steam at 1000 kilo Pascal pressure. So, 1000 kilo Pascal means 10 bar pressure enters a de Laval steam de Laval is a this is de Laval, the de Laval is a impulse turbine and exhaust at 100 kPa that is atmospheric pressure.

There are 4 nozzles in the turbine and each one is inclined at 20 degree angle to the plane of the wheel. So, alpha 1 is 20 degree nozzle inlet angle, the average peripheral speed of the blade is 400 meters per second. So, it is already given u is already given, obtain the best angle for the blades and the blade efficiency if inlet and outlet angles are same blade inlet and outlet angle; their blade inlet and outlet angle. What is the approximate power developed if the area of the throat of this is of each nozzle is 20 mm square?

So, there is a problem which has to be solved it is a; I mean problem which is mixture of nozzle and turbines right. So, first of all we will have to find the velocity at inlet V 1, velocity at inlet of the turbine.

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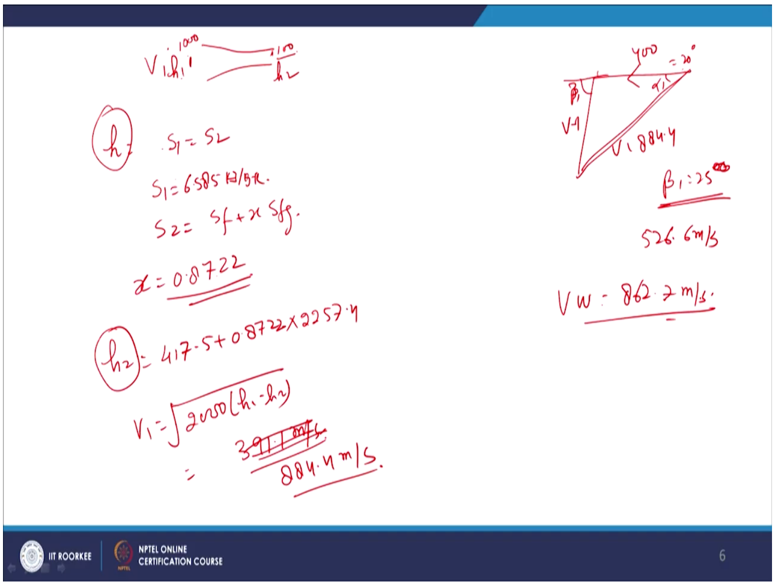

So, for that we will have to go for nozzle equations. So, nozzle up steam is 10 bar or 1000 kilo Pascal down steam is 100 kilo Pascal right. So, we will take h 1 here and h 2 here. So, h 1 is saturated steam at, saturated steam at 1000 kilo Pascal and that is 2777.1 right and because if we do not know the quality at the exit and quality at the throat as well right.

So, first of all we will try to find the quality of the exit. So, quality at the exit if you remember then we will have to take S 1 is equal to S 2 enthalpy at this point, enthalpy at this point they have to be equal. This is saturated, we can take from the steam table.

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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

And this S 1 is, this S 1 is 6.585. So, 6.585 kilo Joules per kg Kelvin right and S 2 is s f plus x s f g, now S 2 we have to take at s f here s f plus x s f g that will give you the value of x. So, here we are getting the value of x s I will not do the elaborate calculations 0.8722; now with this value of x we can find the value of h 2 right.

Now, once we have the value of h 2, h 2 I will write h 2 is equal to 417.5 plus 0.8722 multiplied by 2257.4. These properties you can take from her,e this is h f g and h f 100 kilo Pascal right. Now, once we have the value of h 2, h 1 is already with us we can take h 1 because it is a saturated steam. So, h g we can take from here right. And then V 1 is equal to under root 2000 h 1 minus h 2 and that is going to be 391.1 meters per second sorry this is wrong 884.4 meters per second.

So, this is the value of V 1, now we have calculated the value of V 1, now we have the u, value of u, value of V 1 and alpha. Now, we can draw this part of the triangle and geometrically also using the skills of trigonometry because this is 400, this is 884.4 right and we can easily found the find the value of beta 1. Because, now using the skills of trigonometry we can find because 2 arms are known 1 angle is known.

We can easily draw the triangle or using formulas of trigonometry we can find the value of beta 1 here, the beta 1 is 25 degree; beta 1 is 25 degree. Now, after calculating the value beta 1 we will calculate the value of V r 1, we can easily find the value of V r 1 and the V r 1 is 526.6 meters per second because, once the triangle is drawn all the parameters we can all easily calculate right.

Now, here because be V in the problem it has if inlet and outlet angles are same, blade inlet and outlet angle are same in this case if you take the whirl component of this triangle; whirl competent of this triangle is V 1 cos alpha 1. If you take V 1 cos alpha 1 and multiply it by 2 we will get the whirl component; so, whirl component is going to be 862.7 meters per second.

Now, once we have whirl component with us, now this is about the turbine; now let us go to the nozzle part. We have to find the throat diameter, we have to find best angle to the blades you already find. If the area of throat power we have to calculate the power ok.

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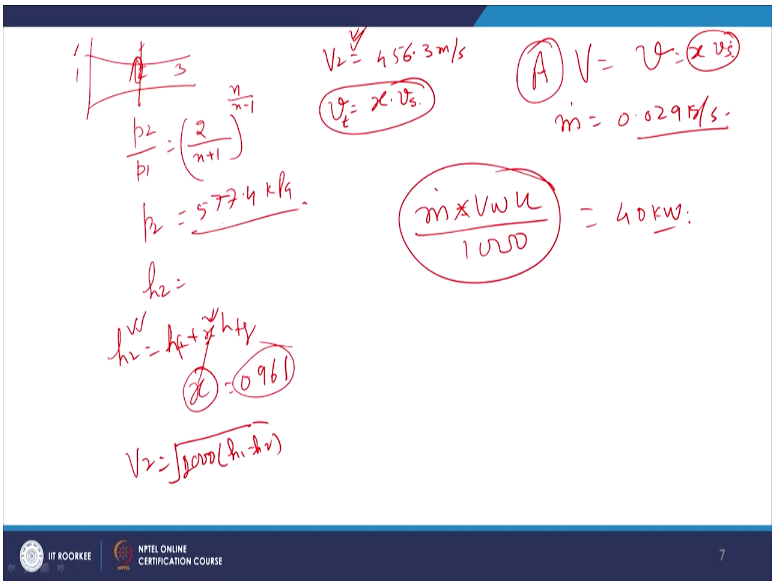

So, for this we will again go for the analysis of the nozzle, this is 1 2 and 3; critical pressure ratio if you remember p 2 by p 1 is equal to 2 by n plus 1; 2 by n plus 1 divided by n over n minus 1 right and here from here we can easily get the value of p 2 as 577.4 kilo Pascal; this is the pressure here right. Now, what we are going to do? From here we will get the enthalpy, once pressure is known we will go to the this table for a particular pressure 575 we will take; we will take the enthalpy.

What is going to be the enthalpy? For enthalpy we need the quality, say for p 2 h 2 is equal to h f plus x h f g. We need the quality, we will do the same exercise; entropy is constant. Entropy is 10 kilo Pascal is equal to entropy at 570 this 7.4 at this pressure and this pressure the entropy is same right; from here there we will get the value of x quality and using this value of quality from here we are getting the quality as 0.961.

Using this quality we will get the enthalpy at stage 2, one h 2 is known h 1 is known. What we are going to do? We are going to get the velocity at stage 2, V 2 right. Now once we have the velocity at stage 2 that is 456.3 meter per second right. We will take the specific volume also at throat. A specific volume at throat is quality multiplied by a saturated vapor specific volume.

Now, why we are doing this? We are doing this to find the mass flow rate for each because we until and unless we have mass flow rate, we cannot find the power output; velocity diagram will give us only the power output let us say per unit mass flow rate. So, in order to find the power output we have to have mass flow rate of the steam, for the mass flow rate of a steam we need the cross section area and cross section area is given only for the nozzle right.

So, for this reason at the nozzle throat cross section at the nozzle; cross section of the nozzle at the throat is given. So, at the throat we have area we have calculated the velocity from using this formula this V is equal to; this V is equal to under root 2000 h 1 minus h 2 we have taken 1000 because specific enthalpies are in kilo Joules.

Now, area is with us, velocity also we have found, specific volume is equal to x v s this we have taken from here 575 so, v f. Sorry v f g v g yes, yes this multiplied by quality of the vapor right; now from here we can find the mass flow rate per unit nozzle. So, mass flow rate per nozzle is 0.029 kg per second. Now, if you look at the numerical how many nozzles are, there are four nozzles.

So, this mass flow rate is multiplied by 4 right. When this mass flow rate is multiplied by 4 you will get the gross mass flow rate, once we get the gross mass flow rate and then multiply it by a v w is known, u is known divided by 1000 we will get the output of the turbine and this output of the turbine here in this case is 40 kilowatts.

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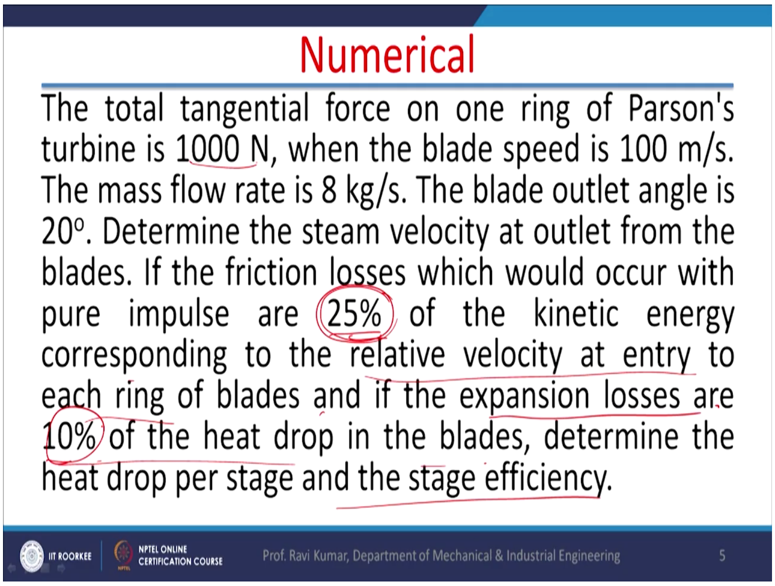

So, this is one numerical I have solved for impulse turbine, now another numerical I have solve for impulse reaction turbine. Now, here the total tangential force is given, total tangential force on a ring of Parson's turbine is 1000 Newton's. Remember in parson turbine the characteristics of the Parson turbine is absolute velocity as inlet is equal to relative velocity at outlet, I explained earlier.

1000 Newton's, when the blade is speed is 1000 meters per second, blade speed is u, the mass flow rate is 8 per kg per second. The blade outlet angle is 20 degree, this is the outlet angle of the blade. Determine the steam velocity at outlet from the blades if friction losses which would occur with pure impulse are 25 percent of the kinetic energy, here 25 carry you this friction losses have come into the picture corresponding to the relative velocity at entry to each ring of blades.

Because, Parson turbine has number of stages. So, here we are talking about one stage, the loss are 10 percent of the heat drop in the blade; determine the heat drop per stage and the stage efficiency ok.

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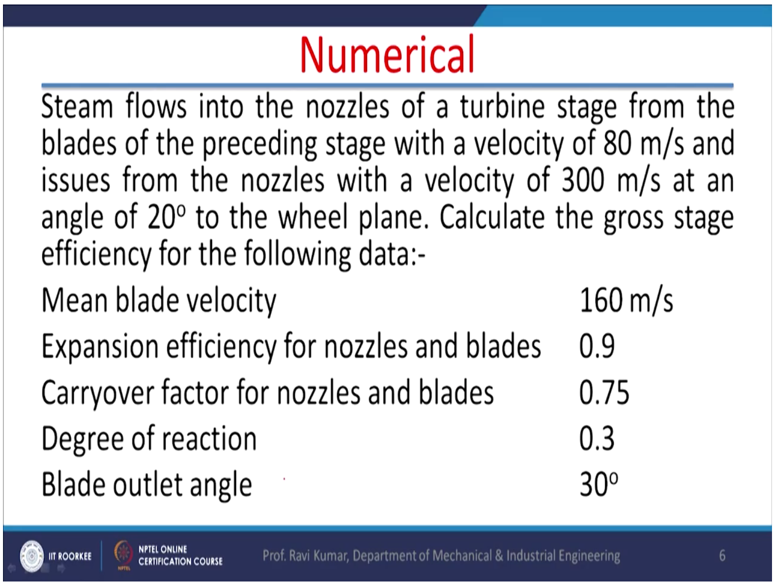

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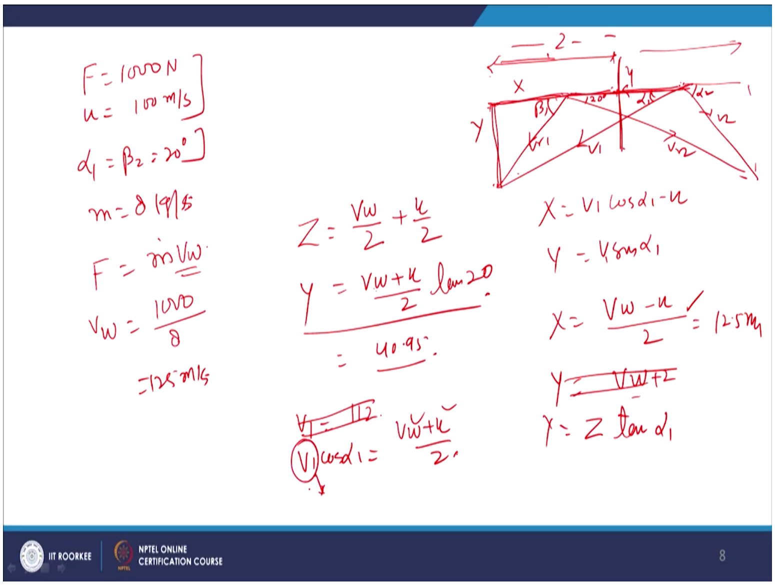

So, for this 4 sorry; so, for this the force is 1000 Newton right which is working on the blades and blade peripheral velocity is u is 100 meters per second. They are two things blade inlet; sorry nozzle inlet angle is equal to blade outlet angle 20 degree, they are all given values in numerical.

Now, F and mass flow rate is also given 8 kg per second, kg per second. So, here now F is equal to mass flow rate into V w. So, from here we can get the value of V w that is equal to 1000 divided by 8, 125 meters per second. If you look at the triangle, velocity triangle for a Parson turbine this is u this is V 1, this is V r 1, this is V r 2, this is V 2 and this is alpha 1 and this is beta 2, they are known 20 degree, 20 degree right.

But, what we do not know? The beta 1, now here in order to find beta 1 let us find the value of X and Y, now the X is V 1 cos alpha 1 minus u. Now, V 1 is known to us sorry yes and Y is V 1 sin alpha 1 right or we can say X is equal to V w minus u divided by; V w minus u divided by 2. X is V w u V w divided by 2 minus u by 2, V w divided by 2 this is V w divided by 2 half of this because the Parson turbine symmetry both symmetry is on the both the sides right minus u by 2.

So, we will get this, Y is equal to V w. So, Y is equal to this plus this tan alpha 1. So, let us take the Z, Z tan alpha 1. Now Z is this length plus this length. So, this length is V w by 2 and this length is u by 2. So, Z is equal to V w plus u by 2 right and this is tan and this will be Y is it going to be tan 20 this tan 20.

Now, from here we will get the value of X; we have the we are getting the value of X as 12.5 meter per second and Y the value is 40.95 right Once we have the value of X and Y we can find the value of beta 1, once the value of beta 1 is known we can find the value of alpha 2 right and the V 1 is; V 1 is V 1 is 112 this is this V 1.

So, V 1 cos alpha sorry this is V 1 cos alpha 1 is equal to this V w u plus V w plus u by 2 this is V w by 2 plus u by 2. So, V w plus u by 2 these values are known, from here we will get the value of V 1.

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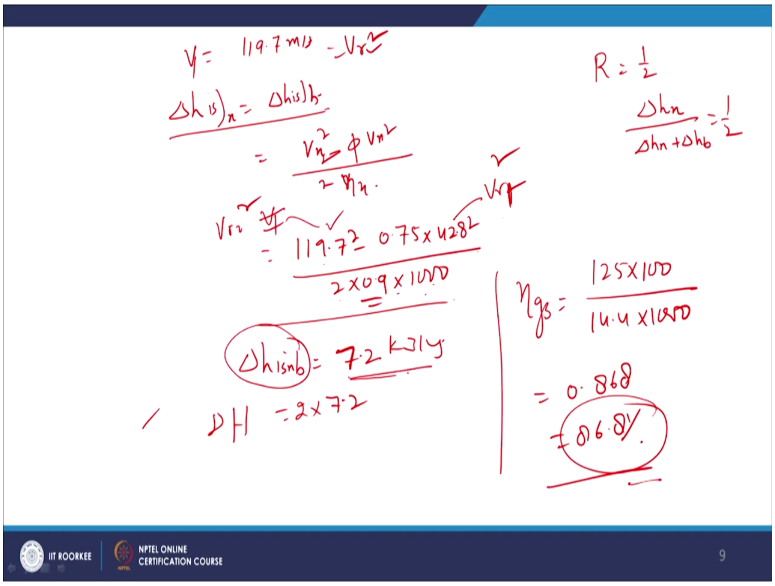

Now, once the value of V 1 is known that V 1 is 119.7 meters per second delta h isentropic in nozzle is equal to delta h isentropic in blades because reaction is, degree of reaction is half impulses turbine. So, delta h in nozzle divided by delta h in nozzle plus delta h in blade is equal to half, from here we can get this expression and that is equal to V n square minus phi V n square by 2 efficiency of nozzle. So, from here we will get 119.7 square minus 0. carry over a coefficient is given point 0. into 42.8 square divided by 2 into 0.9 into 1000, 0.9 is taken from here the expansion losses are 10 percent.

So, 0.9 is taken from here and 42.8 is the velocity this is V r 2 and this is 119 is the velocity V 1 right. So, this is V 1 square minus phi V r 2 square because here right and from here we get the delta h blade s equal to 7.2 kilo Joules per kg. So, total delta h is going to be 2 times 7.2

and here if you want to calculate the gross stage efficiency it is going to be 125 into 100 divided by 14.4 into 1000 and it is going to be 0.868 or 86.8 percent right.

So, the gross stage efficiency is 86.8 percent, this is the last value which was supposed to drive out of this numerical. Here there is a correction, this is V r 2 square and this is V r for the square because carryover coefficient; when we talk about the carry over coefficient this is V r 1 square and this is V r 2 square.

So, this is there is a correction this is V 1 and this is equal to V r 2 in a Parson's turbine. So, V r 2 square minus phi V r 1 square divided by 2 into 0.9 divided by 1000 and this is going to be; going to give us the value as pressure drop; this enthalpy drop in nozzle as 7.2 that is all for today.

Thank you very much.