Power Plant Engineering
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Lecture – 17
Energy Losses in Steam Turbines

Hello, I welcome you all in this course on Power Plant Engineering. Today we will discuss about the Energy Losses in Steam Turbines. As all of you know that no machine is 100 percent efficient.

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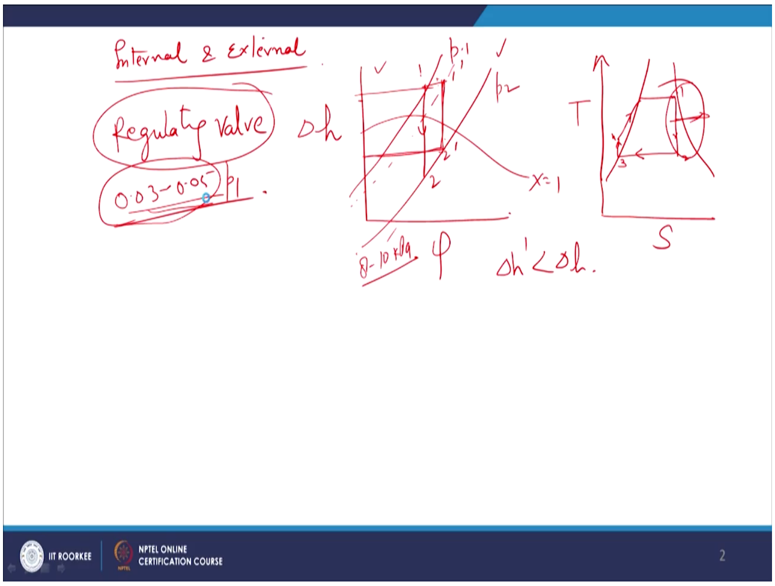

So, is our Carnot cycle sorry this Rankine cycle, if you draw the entire this ideal Rankine cycle on temperature entropy diagram it is going to be like this. There is 1, 2 process of 1, 2 we are expansion steam turbine takes place then 2 to 3 condenser then 3 to 4 pump and then boiler. So, we are confining our discussion to this part of the boiler right where the losses takes place.

In the steam turbine there are two types of losses: internet losses and external losses, losses means the steam which is supplied here does not take part in power generation that we call losses in the stream turbine. So, steam is bypassing this process of producing power. So, this phenomena is called the losses in the steam turbine and the steam turbine. When the steam enters a turbine there is a regulating valve, that regulating valve. It is very much integral part of the steam turbine right. So, it controls the flow of his team inside the turbine.

Since, it is a valve; so, and it has there is, there has to be some pressure drop across the wall. So, the pressure drop is approximately 0.03 to 0.05 p 1. 3 to 5 percent of the inlet pressure right. And what happens when this pressure drop take place, suppose we draw the process on enthalpy entropy diagram. So, there is a constant pressure line p 1 and this is constant pressure line p 2 right. And, there is a saturation line X is equal to 1 right. Now, expansion is taking place inside the turbine and the process is let us say it is 1 to 2.

Now, third link is taking place in third link enthalpy remains constant and pressure is reduced. So, in the pressure regulating valve we will find a new pressure this is 1 dash right. And, when expansion from 1 bash takes place it is 1 dash to 2 dash. So, here you can clearly see that the entry at the entry of the turbine the process the output this delta h. So, delta h dash is less than delta h delta h is 1 to 2. So, actually the we could have we were getting in ideal pulses we are getting worth output from the process 1 to 2. Now, due to third link the pressure at 1 has reduced to pressure 1 dash.

Now, because this pressure is constant this is condenser pressure it is of the order of let us say 8 to 10 kilo Pascal or 15 kilo Pascal not more than that. So, this pressure is constant. So, we can see that steam in enthalpy is less in this case. So, this is a loss right and this loss is due to pressure regulating valve. So, the pressure drop; obviously, the pressure drop in the pressure regulating valve has to be minimized, but normally it remains in the order of 0.03 to 0.04 or 3 to 5 percent of inlet pressure. Now, after entering the turbine steam enters the nozzle.

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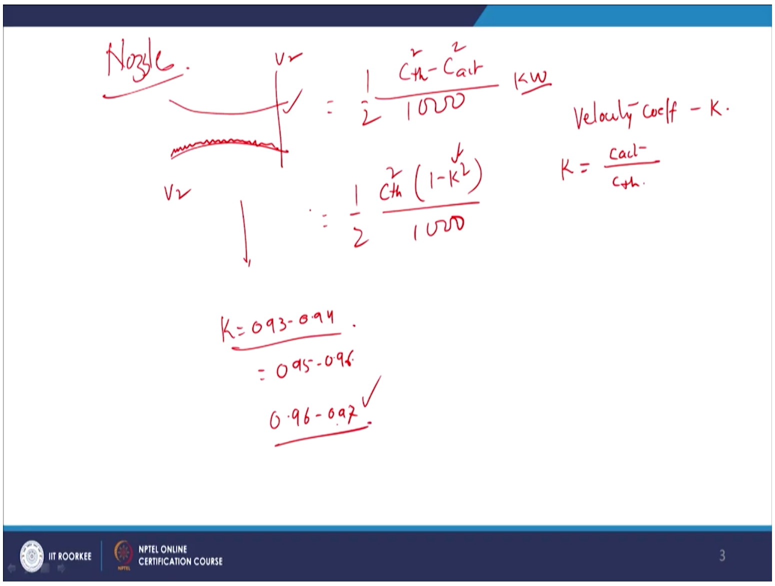

And nozzle does not have any moving part. It is a passage through which steam through which the steam passes. It can be a converter diversion nozzle or conversion nozzle and velocity of steam is increased right, but if there a friction in the nozzle, when there is a friction in the nozzle the exit velocity will reduce, exit velocity from the nozzle will reduce right. There is a friction register in the wall which will increase the ideally it should be isentropic process.

The expansion in the nozzle, but due to friction in the wall it is no longer isentropic process right, heat generation is there. There is a viscous friction between particles also and we assume his steam to be an ideal fluid when we consider it while passing through a nozzle, but it is not an ideal fluid. So, viscous friction between particle is there boundary layer growth is there inside and there are so many phenomena and these all of these phenomena they lead to loss in the nozzle.

So, if there is a theoretical velocity at outlet and there is an actual velocity at outlet. Then we can say this is the losses in kinetic energy and this losses in kinetic energy is directly reflected in the output of the turbine. And, if you divided this 1000 we will get loss in kinetic energy in kilowatts right. There is a term which is known as velocity coefficient which is depicted by K.

So, K is equal to actual velocity divided by theoretical velocity. So, here we can always modify the loss in nozzels as theoretically squared 1 minus K square divided by 1000 right. Now, this K it depends all these facts at factors which I have already explained to you the value of K depends on these factors. If there is a rough nozzle I mean rough or it is a casted nozzle. The value of K will be in the range of 0.93 to 0.94.

Now, if you smoothen the surface right. Suppose, it is further machine after casting the nozzle is further machine. Then it is 0.95 to 0.96. And, it is surface if you keep on improving the surface you can go to up to 0.96 to 0.97 very high surface over we can have the value up to the K up to 0.97 and definitely higher value of K will lead to in mitigation of the losses in the steam nozzles right. Now, after leaving these steam nozzles the steam enters to turbine, turbine blades. And, in turbine blade suppose there is an impulse turbine. So, there is a grid of blades, there are number of blades right.

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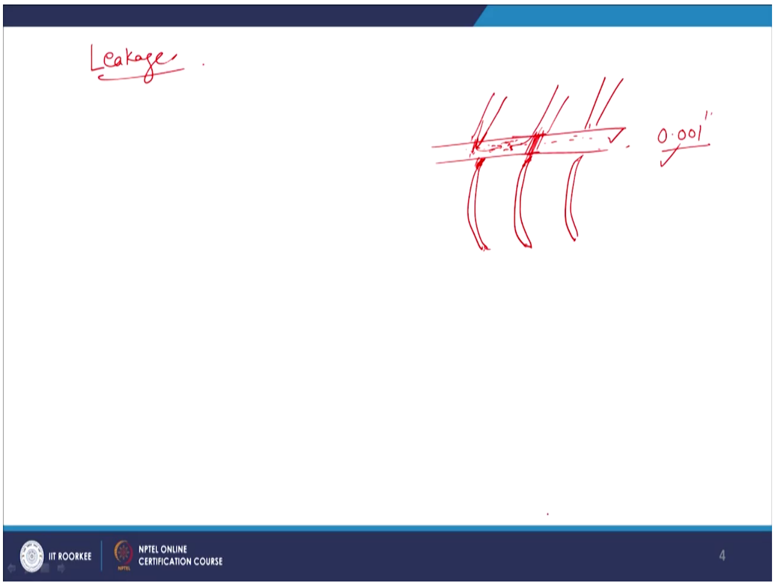

And, there is a gap between the blades and the nozzle and they are nozzles we are fixed throughout the periphery of the diaphragm. Now, when steam is coming from these nozzles it is coming to this space; the space between the nozzle and the turbine blade right. Here mixing of steam takes place this causes ed in this in this part of the turbine. And due to this ed's there is a loss right. Second thing is when this high speed because the velocity of steam is quite high in the steam turbine.

So, with the high velocity steam when it strikes the blade edge, blade edge the dimension of the blade edge you can take as I mean 0.001 inches it is quite thin, but it still when the impudent of this high velocity steam takes place this also causes the nozzle. In fact, the wake is created a wake is created, when there was a flow in this steam and due to this wake the losses place. So, these wake losses are also reflected in the efficiency of steam turbine or efficiency of the process.

Now, this leading edge when steam meets the leading edge here also there are two types of losses one is due to weak second is due to mixing or turbulence created here, third one is impingement of steam on the leading edge of the blade. When impingement of the steam or the leading edge blade takes place as I explained earlier there is a loss there is a loss of energy. Now, there is a leakage also there is at several places there is leakage of a steam. So, there is a leakage of steam for example, if you take in pulse turbine.

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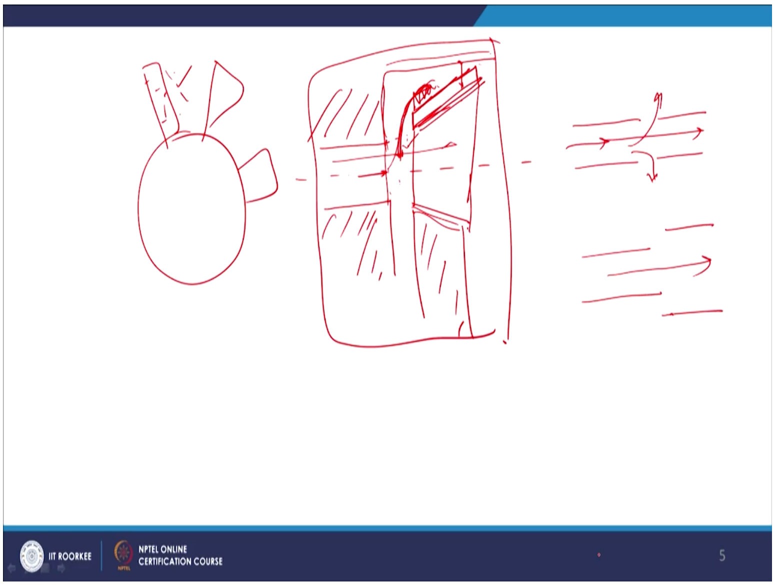

So, suppose the steam is coming from here there is a nozzle exit and there is a blade on this side right. So, this is nozzle and this will go. And, this is the excess of the turbine right. Now, when steam is coming from this side from the it is coming out of the nozzle. And it is entering the blade right. Steam will also try to leave from here there is a shrouding this is a shrouded place, this is a shrouding here. And steam because a clearance has to be provided with the moving blade and the casing I mean there has to be something otherwise the blade will not move at all.

So, the clearance has to be provided and steam tries to bypass through this clearance. Now, how to stop it? Now, in order to stop it one solution is we increase the height of the blade a little height of the blade. When a little height of the blade is increased it more steam I cannot say hundred percent, but more quantity of steam will enter the blade because there are two passes suppose there are two passages like this. One is like this and another is like this fluid is coming from this side right.

So, part of the fluid will enter the other part of the fluid will like to leave from here, but if we increase the width of this passage there is a possibility most of the fluid will move in this direction. So, blade height is increased, but in that case what happens there is the reverse full of steam. There is the reverse flow of steam in this direction right. In that case due to this maybe due to the because the labyrinth seal is provided here in labyrinth seal is provided here and due to this there is a reverse flow of steam in this passage. And this causes again the loss of work.

So, the loss of work; so, the loss of work through leakage in a steam turbine is difficult to avoid. I mean we can minimize it, but we cannot completely avoid it, now the second thing is when steam moves over to the blades right. It fills the entire passage. So, this friction of the blades when there is a blade suppose blades are fixed on the mounted on the turbine. And, when the steam is moving over these blades there is a disc friction I mean the friction between the moving disk and the moving fluid and this also causes losses in the moment of steam turbine.

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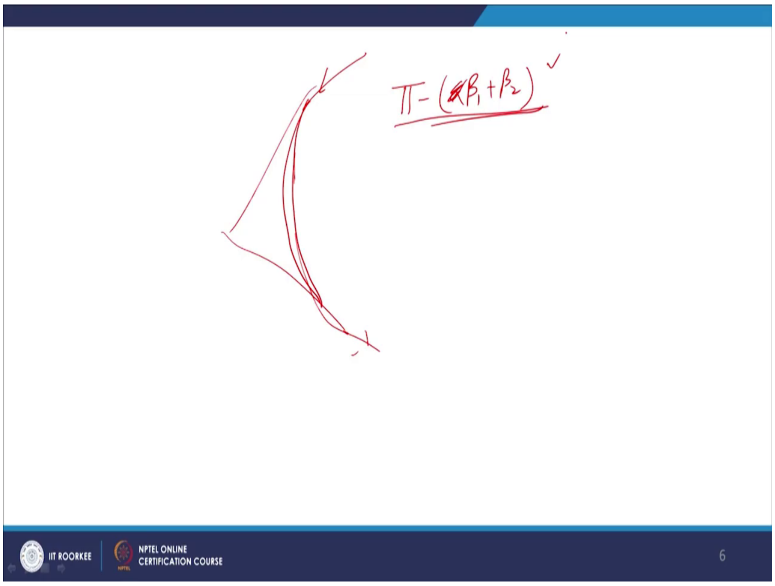

Another thing is when steam strike the blades in a any whether there is impulse turbine or reaction turbine it there is a change in direction of the steam. There is a change inertia, there is a change in direction. When there is a change in direction due to this also the there are losses due to friction over the surface. Secondly, the angle of turn, if you look at the angle of turn is equal to blade angle sorry not alpha beta blade angle inlet plus blade angle and outlet there is the angle of turn right. And, higher the angle of turn more of the losses ok. There are losses due to shrouding also in as I explained earlier. Now, we will focus on the disc friction losses.

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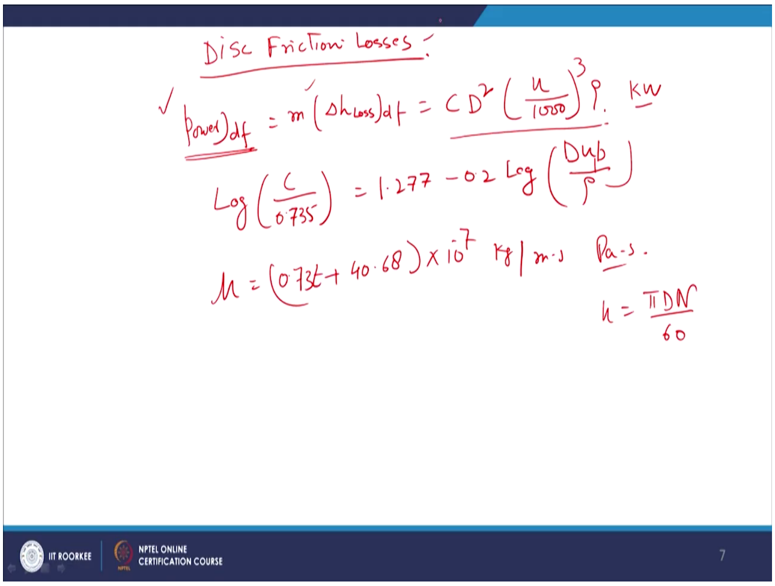

Now, for the disc friction losses there is empirical formula power disc friction is equal to m delta h disc friction is equal to CD square u by 1000 cube root kilowatt. This is the empirical formula, empirical formula are derived by conducting number of experiments on the prototypes and such type of formula are generated to facilitate the designing (Refer Time: 14:14) So, disc friction in terms of power in any turbine can be formed out using this formula we are in another log C by 0.735.

And mu is equal to 0.73 t plus 40.68 into 10 to power minus 7 kg per meter second or we can see Pascal second any of the unit you can use. Now, mu will get from here C will get from here and ultimately we will get the power. Now, D is the diameter of the mean diameter of the rotor, P is pressure u is the peripheral velocity u is equal to pi DN by 60, but through this formula we can because what happens we understand the losses are taking place, but if you can quantify the losses we can classify the losses and if we can quantify the losses. Then we can take the measures how to mitigate these losses in a steam turbine? Right, losses such as steam loss in this steam turbine is the loss of power right.

So, if you minimize the losses definitely we can increase the output of the turbine or we can produce a more efficient steam turbine.

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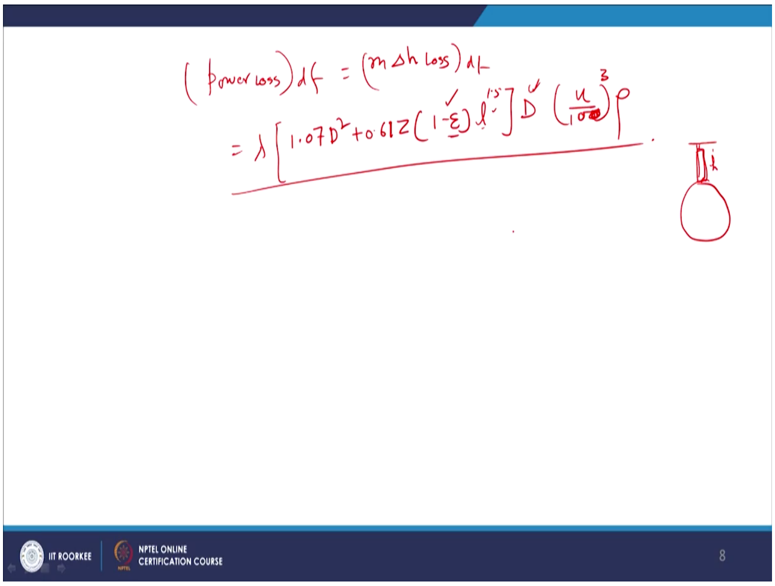

There is another empirical relation for power loss disc friction is equal to m again delta h loss. Disc friction is equal to lambda partial this is partial admission of steam 0.07 d square 0.61Z 1 minus epsilon l 1.5 D u by 1000 u by 100 sorry not 1000 u by 100 cube and rho. This is an this is also an empirical formula, in this empirical formula the length of the blade is also taken into the account. In previous formula in this formula also there is a D this is a mean diameter l is the length of the blade, length of the blade suppose there is a drum shaft, this is the solid shaft blades are mounted on the shaft.

So, this height of the blade is l here and clearance of the blade with the casing is epsilon. So, this clearance is also taken to the account and height of the blade is also taken into the account in this formula. Now, we will talk more about the clearance losses. Now what we do? We provide (Refer Time: 17:16), packing's are provided; packing's are provided to prevent the leakage of the steam, but packing we cannot provide in a moving part aesthetic parts is ok. When there is no movement we can provide the packing, but for a moving part, for a moving part packing cannot be provided. So, what would what is done on the surface.

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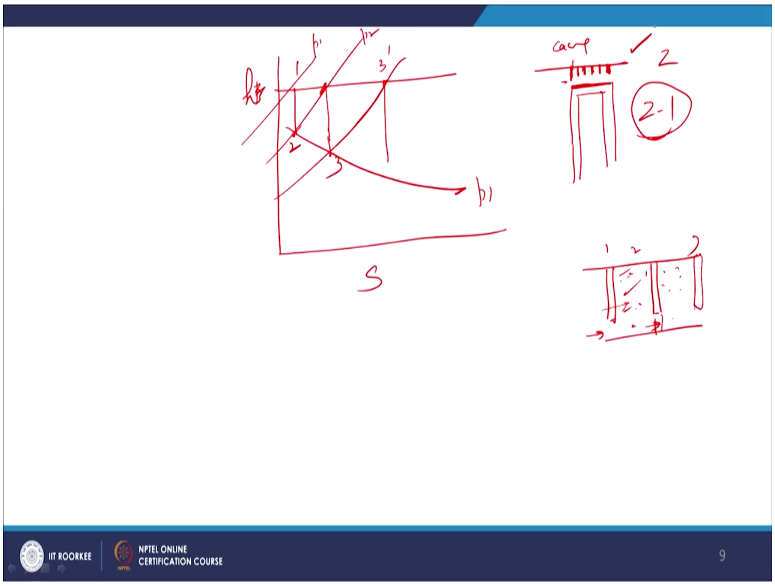

Suppose, this is surface of casing and this is turbine blade end right. So, in this b here constrictions are provided like this. Now, this is a restriction in the flow of steam, but the steam flow we cannot completely restrict because we have to provide this surface as a fluid surface, we cannot extend them up to the surface otherwise a purpose will be lost. So, some clearance is reduced, but it is made sure that the constriction the material of this construction is a very soft material. So, what happens by accident suppose this x this blade comes into the contact of constriction it will be rubbed off, damage will not be done to the blade. Now, in this constriction throttling takes place.

Now, let us b this is the pressure this is p 1 right. So, in one constriction what will happen? When the steam will flow, steam will flow in this direction. So, this is act this part I will magnify this. This part will act as a throttling device. Now, after throttling the steam will come into this cavity right. When the throttling is taking place let us say this is 1; so, 1 and after throttling it comes to the stage 2, now when it comes to the stage here because steam cannot move further in this direction. So, here again the kinetic energy again which is gained here is converted to the pressure energy.

So, in this process it goes up like this somewhere here right. Then again next restriction in this restriction again the expansion takes place on this pressure is reducing. This is h this is h s not pressure this is not pressure this is enthalpy. So, again the expansion is taking place. Now, pressure is reduced here pressure was p 1. Now, pressure has become p 2 right next one 3.

Now, with again the throttling of this high pressure steam will take place. So, at p to two, it will come to pressure 3. Pressure is reduced, now at this pressure again this velocity I mean there is mixing off will take place and because there is no passage to move. Then again we list the enthalpy will be rigid. So, we will attain the is this stage let us say this is 3 dash right. And, this process will continue and we will get finally, we will get pressure p 1. Suppose, number of constriction; number of constrictions are z space between the constriction will be z minus 1, it is obvious.

Suppose, they have 10 constrictions; then the space where, the constrictions will be 10 minus 1 9. So, this is another method of preventing the leakage of the stream from between the moving part and the static part. This is because this is the most I mean this is the most typical part in the steam turbine when the rotor is moving and in that case we have to minimize the steam the loss of steam to the surroundings. Now, we will take a case when steam is passing through a restriction. We will just we have to quantify it for the design purpose.

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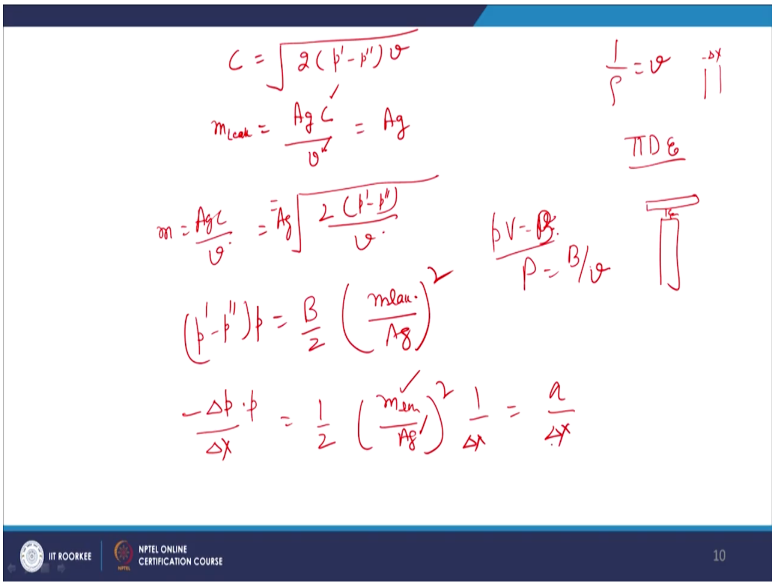

So, the velocity C is equal to under root we know that 2 p dash minus p double dash multiplied by v. v is the specific volume or we can simply we can take divided by rho because 1 by rho is equal to v. So, the velocity after passing one constriction the velocity gate is going to be this, mass of the leak is going to be Ag c divided by v right. Now, Ag is area through which it is passing it is pi D and gap between the casing and the blade, this is epsilon right. c is the velocity, v is the specific volume.

So, it is going to be equal to Ag 2 p dash minus p double dash divided by right. We have simply put the value of this is m leakage is equal to Agc by v, we are getting this expression. Now, as we know that pv is equal to constant. p v is equal to b or p is equal to b by v it is considered to be a constant temperature process. So, B by v and this will give us p dash minus p double dash multiplied by P is equal to B by 2 m leak divided by 2 A g whole square.

It is simple algebraic manipulation nothing else, from here we can get this is p minus p dash minus p double dash. It is negative of pressure drop. So, we can say delta p multiplied by p. Let us divided it by delta x. This is the distance the delta x right. And it is going to be equal to half m leak divided by Ag whole square 1 by delta x and we can say it because this is constant, mass league is constraint this is constraint. So, we can always say it is a by delta x.

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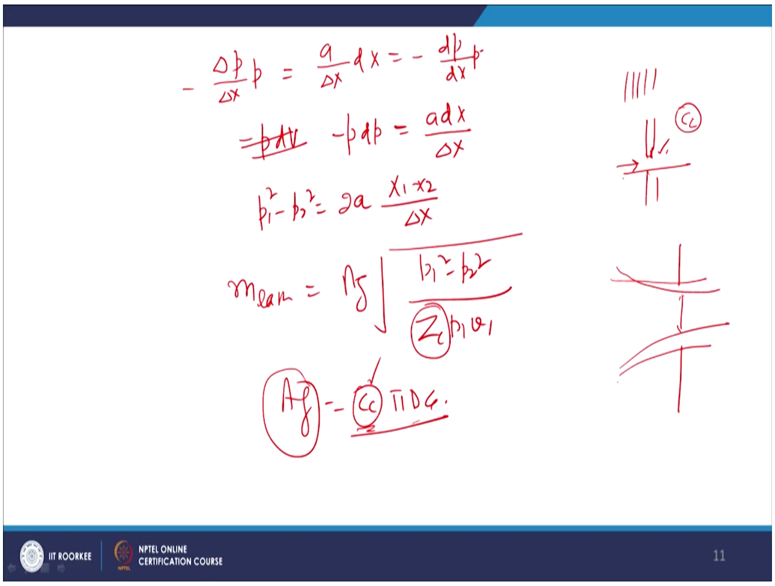

I am writing it again delta p by delta x multiplied by p is equal to a delta x d x is equal to minus d p by dx multiplied with b. Now, if you further manipulate this will get minus p d p sorry minus p d p is equal to adx divided by delta x or p 1 squared minus p 2 square is equal to 2 a x 1 minus x 2 divide delta x right.

Now, if you further do the manipulations we will get m leak as under root p 1 square minus p 2 square divided by z p 1 v 1. Now, why we are talking zc? This is the number of restrictions as I said earlier. Now, this is Ag is equal to C c pi D epsilon. Now, C c is constriction coefficient because when there is a restriction and the steam is flowing to this restriction. There is a coefficient which has to be multiplied by which should multiply the theoretical velocity output; so, that we can get the actual velocity output right.

So, this coefficient has to be used in order to find the value of the Ag because, if you have if you know the villa contractor. Suppose the fluid is passing through a restriction fluid will not move like this, there will be neck formation here and which will reduce the cross section area right. So, this reduction in cost section area is taken into the account by C c. Now, this is for the velocity when the velocity is a subsonic.

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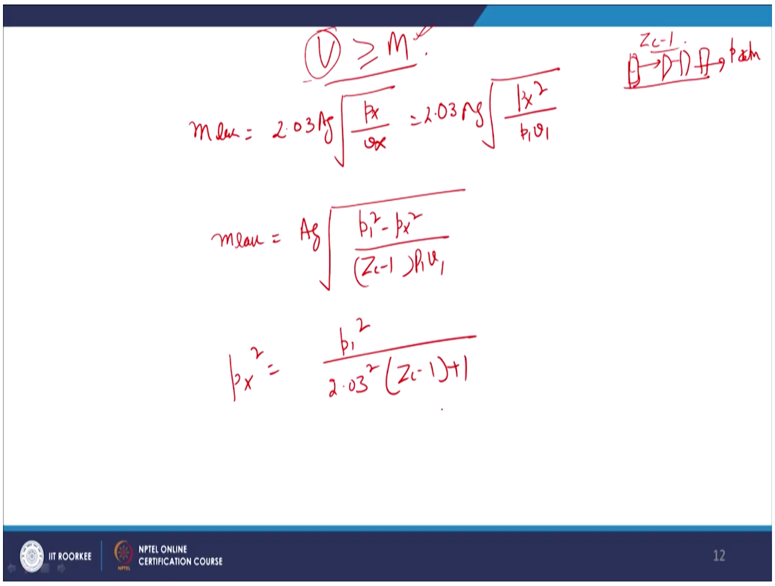

Now, suppose the velocity is supersonic right or the velocity is greater than or equal to there is convergent divergent nozzle. So, when there is a convergent divergent nozzle there is a equation for convergent divergent mass flow rate through a convergent divergent nozzle. That is 2.03 Ag under root px by vx or we can write z 2.03 Ag under root P x is squared divided by p 1 v 1, because px vx there it is going to be p 1 v 1. So, this px and vx this is the last chamber. There are a number of constriction we are talking about the last chamber because after the last chamber there is atomistic here.

So, these details we are talking about the last chamber because here the velocity will also be high and we can consider here the case of convergent divergent nozzle. So, m leak is going to be p 1 square minus p x squared divided by z c minus 1 p 1 v 1. Why we saying Z c minus? Because there are Z number of constriction; then the gap between the constriction is going to be there to Z c minus 1 right. And, from here we can get the value f px is squared as p 1 squared divided by 2.03 is square Z c minus 1 plus 1.

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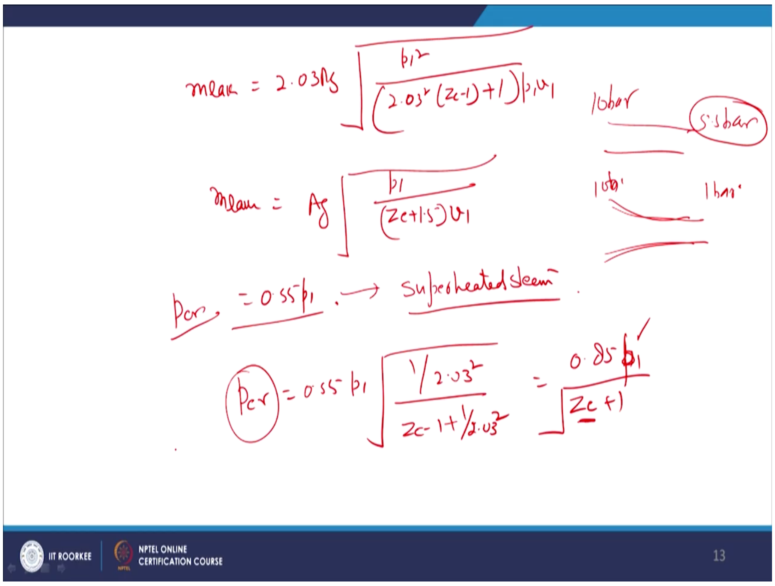

Or m leak is going to be 2.03 Ag under root p 1 squared divided by 2.03 whole squared z c minus 1 plus 1 p 1 v 1 or we can say m leak is equal to p 1 Z c plus 1.5 v 1. Now, in a convergent divergent nozzle there is term which is known as critical pressure right. And, critical pressure is always 0.55 p 1. It means if up steam pressure is 10 bar the critical pressure is going to be 5 bar or 9 stream. Suppose, there is a nozzle which has up steam pressure of 10 bar and downstream pressure is 1 bar right.

So, it is going to be a conversion diversion nozzle because the critical pressure we are getting here is 5.5 bar same is the case here. So, right and we are considering here this is for super heated steam, this is for the superheated steam. So, critical pressure is equal to 0.55 p 1 under root 1 by 2.03 square divided by Z c minus 1 plus 1.2.03 whole square is equal to 0.85 p 1 by Z c plus 1 under root. Now, this is p 1. So, if we know the value of p 1. If we know the value of Z c number of constriction we can easily find the critical pressure.

Now, once the critical pressure is known we can find the leakage through the type of leakage I mean which part of the (Refer Time: 30:02) is having subsonic considered to be subsonic and which part of the packing has to be considered as supersonic. Now, there is one special case I would like to discuss here that is leakage in impulse reaction turbine. In impulse reaction turbine as you know they are fixed blade and the moving glades.

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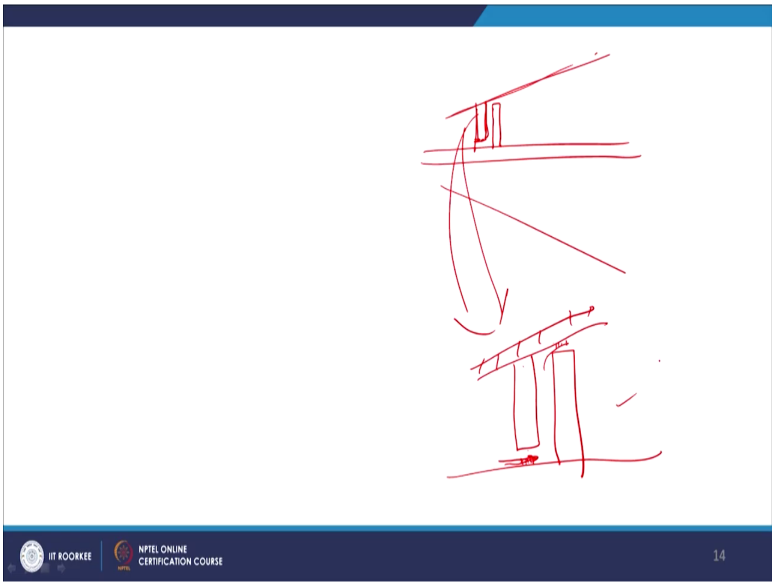

So, fixed blades are fixed on the housing, this is shaft. So, fixed blades are this is not up to here it is up to here only. Fixed blades are arranged in the housing and the moving blades are in on are mounted on the router. So, here in this case what happens if I am a magnify this it is going to be something like this right. And, the leakage will not only take place from the between the casing and the blades, it will also take place from the fixed blade and the shaft between this blades also.

So, we can provide the shrouting here constrictions here and here as well or this is a special case of impulse reaction turbine their external losses also, external losses are less I mean if you look at the turbine external losses.

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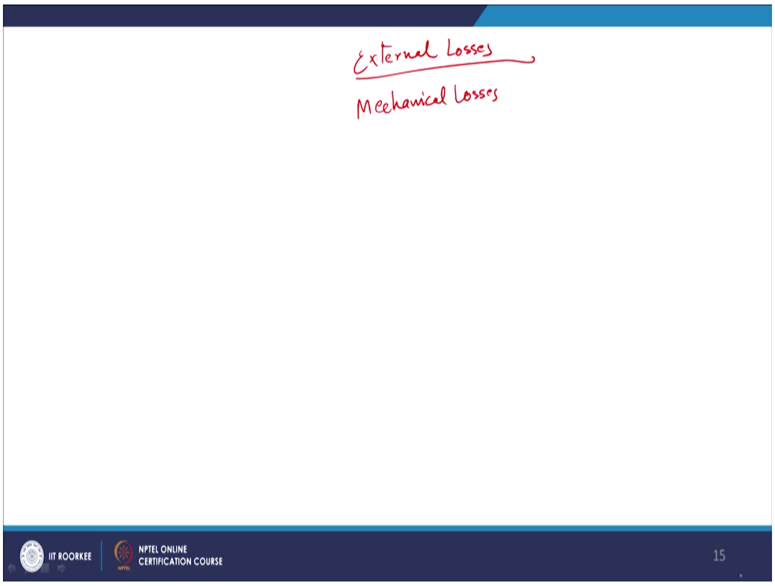

This is mechanical losses movement of the bearing some of the losses in the bearing and losses in the moving parts. So, there mechanical process and leakage of steam, if there is any joint or some I mean opening is there from where the steam is leaking. So, that leakage is also considered as the external loss in the turbine, but it is definitely true if we can quantify any how we can quantify though it is difficult, but anyhow if he can quantify these losses. Then we can plan the minimization of these losses and improving the efficiency of a steam turbine, that is all for today.

Thank you very much.