Power Plant Engineering
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Lecture - 14
Steam Turbines

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

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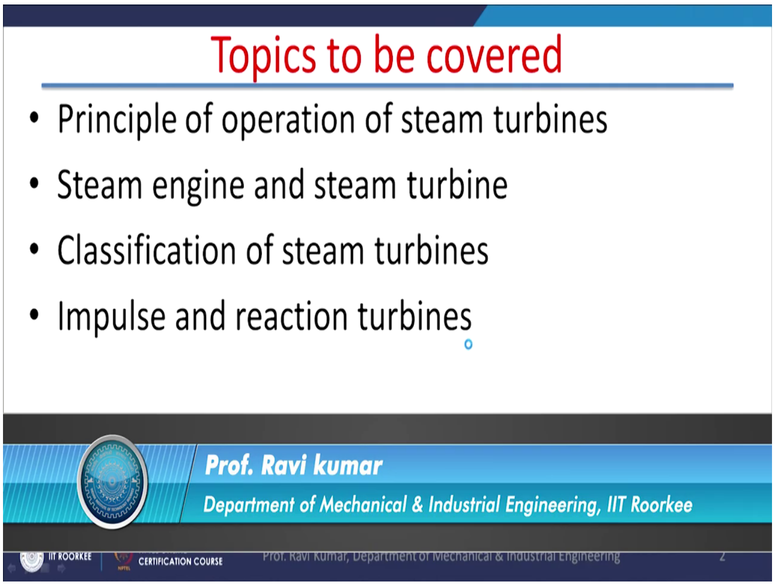

And topics which are going to be covered in this lecture are principal of operation of the steam turbines, steam engine and steam turbine. We will make a comparison between steam engine and the steam turbine; because steam engine was the first device which converted heat into the useful work.

So, we will compare the performance of steam engine with steam turbine. Classification of a steam turbine we will discuss here and a working of impulse and reaction turbines. So, steam turbine is an integral part of any thermal power plant where water is the working fluid; because in a Rankine cycle if you draw a Rankine cycle on temperature and entropy diagram this is temperature and this is entropy. So, this is Rankine cycle right; simple Rankine cycle ok.

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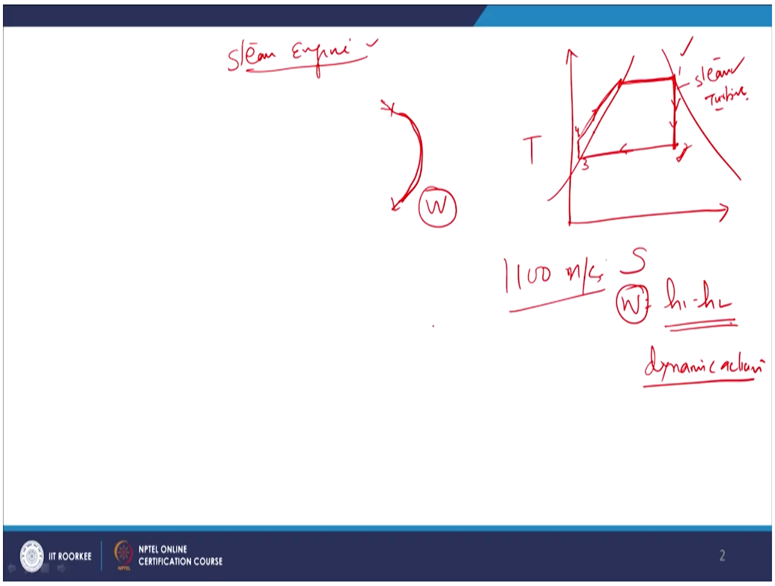

If we want to show the compressor work, then it is going to be like this right. So, state 1 to state 2, 2 to 3 takes place inside the condenser, 3 to 4 pumping of the water now, 4 to 1 is heating in the boiler. So, if the boiler sensible heating and the latent heating both takes places. And after that the expansion of steam in a turbine, it is in a turbine and here the steam turbine is fixed.

If steam turbine is a rotor dynamic machine right and it converts; I mean the low grade energy or the enthalpy of steam high pressure steam to the useful work is extract the work and then exhaust we get steam with the low enthalpy. So, the work of the turbine is if we consider turbine as a as an open system, then it is going to be h 1 minus h 2. This is the work output of the turbine is h 1 minus r 2; enthalpy at state 1 minus enthalpy at state 2 in a steam engine.

For example, if you take a steam engine, what happens in the steam engine? In the steam engine there is a movement of the system boundary the piston compresses the steam and then expansion steam enters the cylinder, then piston moves in this direction. So, there is a two end flow motion of the piston which constantly change the control volume. However, in the case of a steam turbine, the control volume is fixed, the output we get by the dynamic action of this steam.

Here we get dynamic action of the steam; however, in the steam engine it is by virtue of high pressure on the steam right; steam pushes this piston back and then the power is produced. Here in this steam turbine steam glides over the blade surface; it does not strike t the blade, it glides over the blade. And due to change the direction of the velocity of the steam, there is change in the momentum and this change in momentum causes the force.

So, this is the basic difference in the working principle of a steam engine and the steam turbine. Because in the steam turbine the velocity of steam is very high; I mean the steam which is entering the turbine may have the velocity of let us say [FL] sorry 1100 meters per second of that order and with this high velocity, if it strikes the blade it will damage the blade. So, it is always ensured that when steam is entering the blade, it simply glides over the blade surface.

When it glides over the blades surface, there is change in the direction of the steam right. When there is a change in the direction of steam, there is a change in momentum of this steam. And when we calculate the rate of change of the moment of this steam, we get the work output this is how the steam turbine works.

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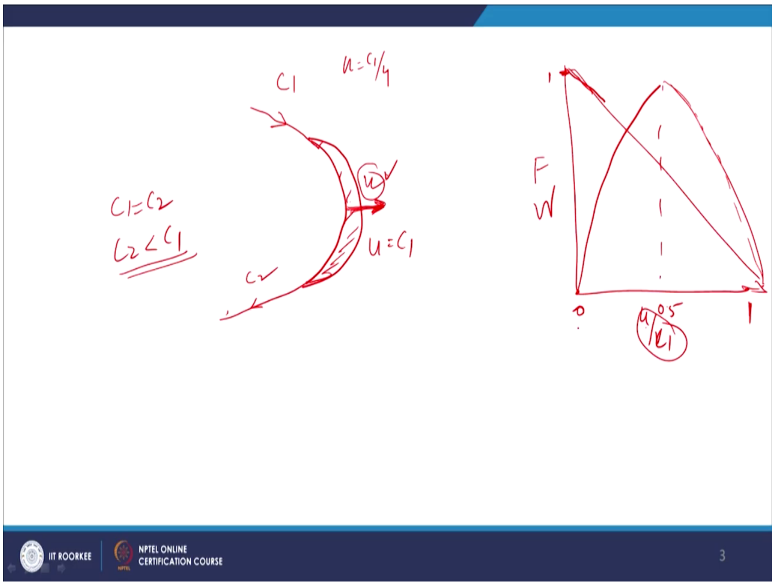

Now, the issue is suppose there is a blade, suppose there is a blade steam entering from the say if steam will never enter in this direction, it will enter from this side along the blade curvature. So this is blade and leaving this side from the blade and blade is fixed; blade is not moving when the blade is not moving then this is velocity C 1 and this is velocity C 2 and C 1 is equal to C 2.

When the blade is not moving, we will get the maximum force. Now, suppose blade starts moving with velocity u suppose u is C 1 by 4 or C 1 by if you draw a graph between a force and a velocity ratio u by v 1 C 1 this is u by C 1.

So, u by C 1 is 0; I mean when u is 0 then u by C 1 is 0 in that case force is going to be the maximum 1. Now, blade also moves in this direction because until less the blade moves, we will not get any output. If blade is rigid and steam is gliding over the blade though it is exerting the force, but there is no displacement; there is no work. The work will come from the displacement, work will not come from the force right.

So, displacement has to there so, displacement means blade should move. And the when the blade is moving with the velocity u; suppose it starts moving slowly with the velocity u maybe C 1 by 4 or C 1 by 10 in that case, this C 2 will be less than C 1. If you look at the energy conservation point of view the kinetic energy at inlet is equal to kinetic energy at outlet where there is no energy dissipation in this direction. When there is a dissipation of energy definitely C 2 will be less than C 1; in that case the force will reduce right.

So, when the u is starts increasing, F is starts when u become C 11 when suppose u becomes C 1 in that case the force will become 0 we will not get any output. So, we will not any output when this is a rigid or not moving at all in that case work output 0 and if the steam velocity is going to blade velocity. So, steam will simply not glide on the blade right, moving in the C velocity relative velocity is 0 so; in that case also the force is 0. So, u by C 1 when u by C 1 is 0 and u by C 1 is 1, then there is a the force is 0.

Now, let us talk about the output. Now we start getting when there is a movement in the blade, initially the output is 0 because there is no movement of the blade where the blade is rigid. If we are getting maximum force, but the blade is rigid blade is not moving. But blade is starts moving we start getting output work output. And work out is output is maximum when this is half right; because it is a product of displacement and the force. Subsequently, when u by C 1 exceeds 0.5; it starts decreasing and it also turns to be 0 and u by C 1 is equal to 1 right.

This is the basic principle of the working of any steam turbine. Here what happens, there are two types of turbines impulse turbine and impulse reaction turbine. Now in impulse turbine, pressure drop does not take place in the blade passage and impulse reaction turbine, pressure drop also takes place the blade passage that we will discuss later on.

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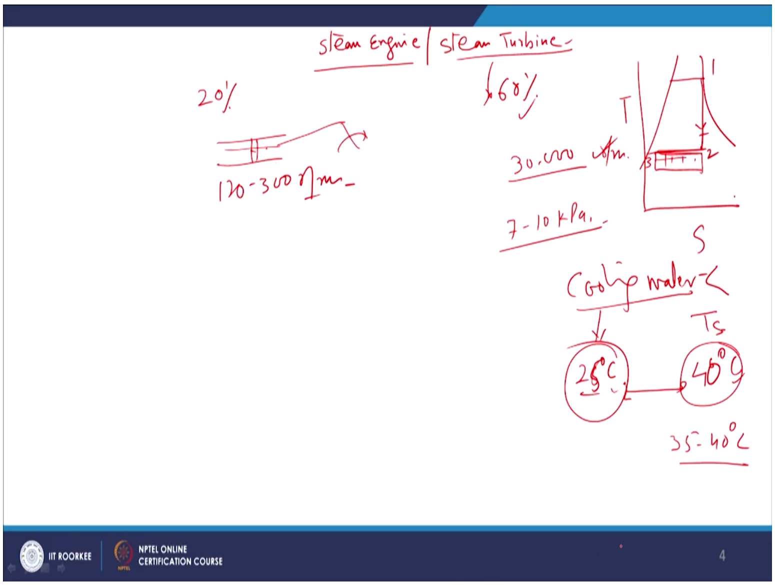

Now, first we will compare because steam engine with steam turbine versus steam turbine. First of all efficiency, steam engine has only 20 percent efficiency 20 percent is good; I mean 15 percent, 12 percent here the efficiency is 60 percent substantially high. Steam engine has reciprocating parts, it has ladder (Refer Time: 09:19) mechanism and reciprocating parts the reciprocating motion of the piston is converted into the rotary motion and it is rotary machine. So, there is no issue of balance unbalance force or the efficiency or any sliding.

So, sliding parts are minimum right and it is a rotary machine. So, that is why the efficiency is high the losses are less. RPM of steam engine is very low rpm steam engine may vary from 120 to 300 maximum 300 rpm steam engine right. If you look at the steam turbine, it goes up to 30,000 single stage steam turbine can go up to 30000-40000 rpm, it is quite high. Lubrication is required in steam engine steam turbines lubrication is not required right.

Maintenance because there are less sliding part in the steam turbine; maintenance is less; in case of a steam engine the maintenance more maintenance is required. And the most interesting thing is in the steam engine, the back pressure is the atomistic pressure this team is exhausted to the atmosphere. Now, here we have condenser and if you look at the Carnot cycle sorry this Rankine cycle temperature entropy. Now expansion of steam, here we use condenser here 2 to 3 and condenser pressure is 7 to 10 kilo Pascal absolute pressure.

So, it works under high vacuum ideally it should be 0 0, but it cannot be 0; not only for the reason of thermodynamics, but for some practical reasons also. Because it condensers we use cooling water because how steam is condensed a steam is condensed in a condenser with the help of cooling water right cooling water.

So, temperature of cooling water has to be less than the temperature of a steam, only then we can condense the steam right. And when the cooling water which is available at let us say 25 degrees centigrade so, steam temperature has to be around 40 degrees centigrade only then we can condense this steam.

If we reduce this temperature difference condenser size will increase, more surface area will be required. If he increase that this temperature difference, then we can reduce the size of the condenser, but power output has to be sacrificed. So, a good compromise has to be made between these two right.

And normally the steam condenser pressure condensing a the steam temperature is maintained between 35 to 40 degrees centigrade depending upon the availability of cooling water. And the last thing is coupling of with the generator; the steam turbine is easier for the steam turbine is easier than a steam engine of. So, clearly the steam turbine is more useful for power generation or purpose then the steam engine.

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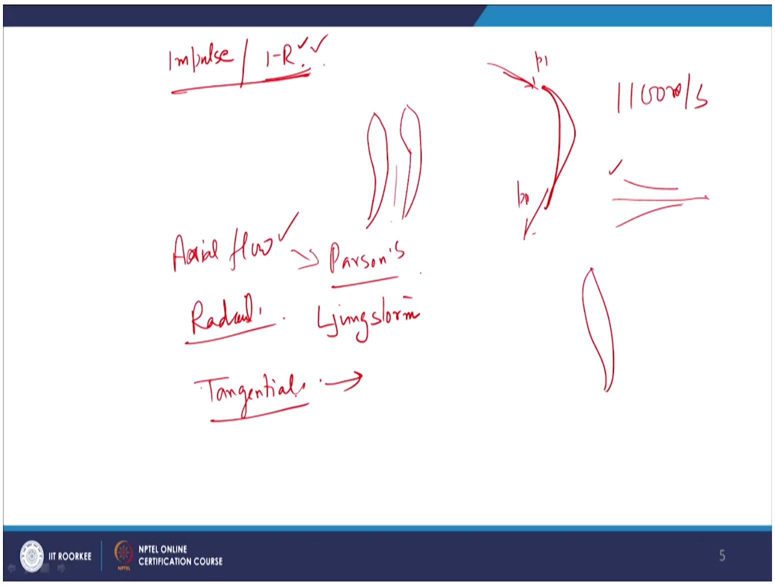

Now, there are different type of steam turbines, first of all I as I explained to you impulse and impulse the reaction turbine. Now, impulse turbine is that turbine where when the steam enters the blade channel, there is no pressure drop. So, when the steam entering from this side that pressure p 1, it will leave this side air pressure p 1 only.

So, whatever the pressure drop takes place it takes place inside the nozzle; because in impulse turbine nozzles are used. So, nozzle the function of the nozzles is to increase the in kinetic energy of a stream at the expense of potential energy. So, first law of for open system also applies for the nozzle. So, if there is a nozzle right so, it has a potential energy potential; if it is horizontal nozzle change in potential energy 0, then pressure energy and kinetic energy.

So, here at the entry the, we assume negligible velocity at the exit there is the pressure drop due to this pressure drop the kinetic energy of the working fluid the steam increases. And with this high velocity as mentioned earlier it can go up to 1100 meters per second. So, with this velocity steam enters the blade, it glides over the blade and leave the blade.

The impulsive reaction, now reaction what is reaction turbine? In reaction turbine this passage is not uniform right. And air fall type of blades are taken; a air fall type of blades are taken right. So, passages is not uniform, this passage area is not uniform and expansion of a steam takes place inside of the passage also right and this causes reaction. So, it has impulse action and reaction action, both action. So, that is why it is called impulse reaction turbine. Nowadays most of the turbines are impulsive reaction turbines.

In addition to this, we can classify turbines as axial flow turbines, normally most of the turbines are axial flow turbines; because in axial flow turbines suppose this is axis of this is the shaft axis steam will move in this direction right. And this shaft axis will have blades, we will have blades like this blade had legs at different places right.

So, when steam sorry blades will be like this is shaft the blades will be like this at different places when steam will glide over to the blade; it will push the blade in this direction right. Well, suppose steam entering from here it is gliding over the blade, it is pushing the blade in this direction and this will cause torque on the shaft and shaft will move in this direction right so, this is how the axial flow.

So, most of the turbines are axial flow turbines. There are certain turbines which are radial flow turbines also. The blades they are fix and moving blades are in a radial direction and there are certain tangential turbine, where the steam enters in a tangential direction those turbines are I am in the small capacity turbines. And normally they are used for running the auxiliaries in the power plant not the main power plant.

So, we can say axial turbine is parson's turbine parsons turbine axial turbine sorry, the radial example is Ljungstrom Ljungstrom turbine. But these what we call the axial radial tangential turbine they are not very efficient. And as I said earlier they are used for normally running the auxiliaries in a power plant.

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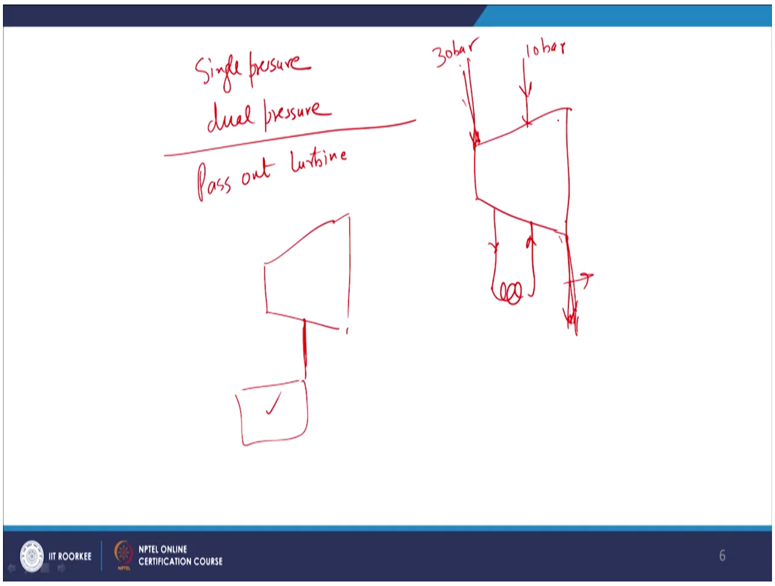

Now, in addition to this, we can do the classification single pressure and dual pressure or reheated turbines. So, single pressure means a turbine just getting steam at high pressure and at a low pressure the steam leaving the turbine the single pressure turbine. But we have we can have two also inlets also, now this will become due late suppose steam entering here at 30 bar steam entering here at 10 bar. And when both the; I mean streams are leaving from here to the condenser at certain atmospheric pressure.

So, this is type of known as dual turbine we can have turbines, we can blend steam at some point heat it and then reenter it this steam this is known as reheat type of turbine. There is a value another type of classification can be there is a turbine which is known as pass out turbine or extraction turbine.

Now, in extraction turbine, this is the during the expansion the steam is trapped at a certain point and it is used for certain processes in the industry right. Similarly, back pressure turbine back pressure turbine the exhaust of the turbine does not go to the condenser it go for the for example, back pressure turbine are normally used in sugar industries ok; where the steam at low pressure is required. So, power is generated in the turbine at the exhauster turbine is sent for the process. So, these types of turbines are a known as back pressure turbines.

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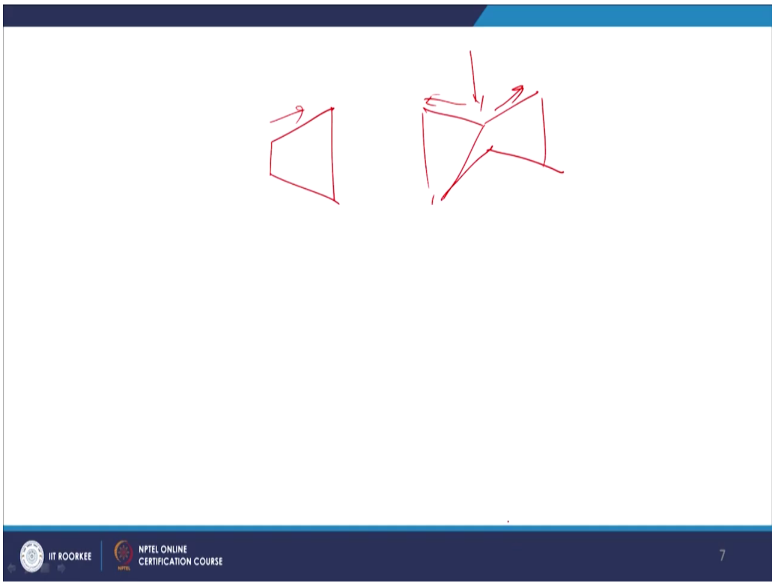

Now, after that we can also classify turbines as single flow turbine; I mean the flow is taking place in one direction the single flow turbine or you can have sorry this double flow turbines steam entering from the middle and moving in two different directions double flow turbine. Reverse turbine is also there when we moving in this direction, then steam reverse back that is known as reverse.

So, we can have a number of classification from steam turbine. Normally and they can I mean if there is a has to be done banking of the turbine we can have tandem that is known as compounding of turbine. What happens in the single stage turbine, if you take a impulse turbine I will draw a diagram for impulse turbine then it will be more clear.

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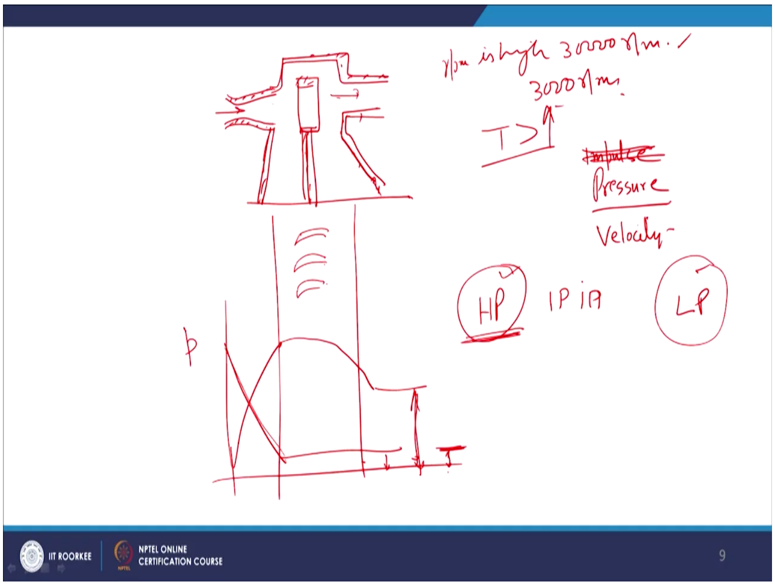

Suppose in a single stage turbine, there is a nozzle and from there is a nozzle. Nozzle will increase the velocity of high pressure steam and then this is k c and then this steam will pass over a turbine blade and this is turbine blade and then it will go to that exhaust. So the steam is entering from here.

So, when steam is entering from here, the velocity of steam is increasing pressure is falling right. Now when the steam is passing over the blade the pressure is remaining constant pressure is remain constant. And what is happening to the velocity? Velocity is also getting reduced and at the exit this is the pressure and this is the velocity right. And we have a series of blades here right now here what is happening; a lot of energy is going wasted.

So, there are two things which are happening steam turbine rpm is high rpm let us say 30,000 rpm and it is quite high; for generators we need 3000 rpm. At the same time kinetic energy of the steam which is leaving the passage is quite high. So, in order to avoid this or in order to address this problem compounding of stages is done ; it means the pressure drop does not take place at one stage it takes place in different stages.

So, we will have array of this combination nozzle turbine blade, then nozzle turbine blade, nozzle turbine blade. So, what will happen? That part of the pressure will fall power output will be then given the exhaust of this will go to the next nozzle right, then pressure will fall kinetic energy will increase the powder will be generate this is known as compounding of turbine.

So, because the pressure does not fall in one stage, in that case and for every stage; so, suppose there are n number of stages so, for every stage the pressure drop the pressure ratio has reduced right. For this reason the rpm will reduce right but we have increased the number of stages. So, from each stage we will getting some power.

So, power will remain same, rpm will reduce it means torque will increase. Torque which is developed on the shaft will increase rpm will reduce power generation will remain same. And you will find at the exhaust of the compound compounded pressure compounded steam turbine. The velocity of exhaust is very low. So, efficiency is also very high right.

So, there are two types of compounding one is impulse compounding and we are in the pressure sorry the pressure not impulse compounding. Pressure compounding, where pressure drop takes place in number of stages another is velocity compounding; where velocity drops in the number of lead stages.

So, there are two types of so in velocity compounding there is only one nozzle and the velocity falls in number of stages. And when the velocity when the expansion takes place because it in later stage the pressure is low, the volume of this steam keeps on increasing specific volume of steam keeps on increasing.

So, in every power plant, suppose in a normal power plant there is no single turbine there are I mean high pressure turbine they are known as HP turbines, there are low pressure turbines this is known as LP turbines and in between there are intermediate pressure turbine IP. So, there can be IP 1, IP 2, LP 1, LP 2 depending upon the output of the design of the power plant and the output of the power plant they can have these turbines in each turbine and will have number of stages. Now, by visual observation you can judge which one is the high speed turbine which one is the low pressure turbine because it HP turbine because mass flow rate is same.

So, in a high pressure turbine the density of the steam is high on a specific volume of the steam is low. So, size of the turbine will be less smaller it will be smaller in size it will be smaller in size. If you look at the low pressure turbine and it will be larger in size. So, just by visual inspection you can judge which one is the low pressure turbine, which is in is the intermediate and which one is the high pressure turbine.

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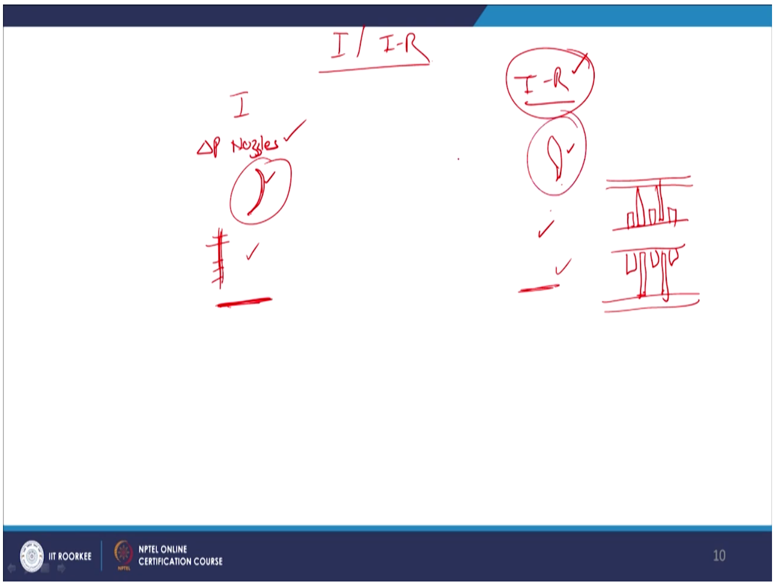

Now, we will discuss a specific difference between impulse and impulse reaction turbine impulse and impulse reaction turbine the basic difference. In impulse turbine, pressure drop takes place only in nozzles right. Impulse reaction turbine it takes place in the moving blades as well, here the moving blades no pressure drop takes place. Impulse turbine as constant blade channels blade channels are simple in impulse turbine; here there is a air file channels so, is a little complicated geometry.

So, their profile type of blades, their air file type of blades, in impulse turbine there can be a partial admission also; I mean all the nozzles have their steam does not have through the all the nozzles. If you want to control the output we can pass the steam through certain nozzles and we can control the output ; higher for in the in this case there is all rounded admission in this impulse reaction turbine the. The admission of the steam has to be all round.

There are other methods of controlling the output but as far as the admission of steam is concerned it is all round admission of steam in the turbine. Here in this case the diaphragm there is a diaphragm which has the nozzles and here impulse reaction turbine they are fixed blades. So, there are two types of blades, one type of blades, which are fixed on the rotor and there is our fixed blades also which are fixed on the casing; they are do not touch the rotor.

So, when the rotor moves, these blades remains fixed this is how the we attain the fixed and the moving blades and these blades they rotate with a certain speed. So, power as far as the power is concerned very high power can be generated by a impulse reaction turbine. This turbine occupies less space for the same power.

So, power space requirement is more for impulse reaction turbine. And; obviously, blade manufacturing is easier for impulse turbine; because and here because they are profile type of blades and here the blades are air fall types. So manufacturing is little difficult and if you compare with the manufacturing of impulse turbine blades.

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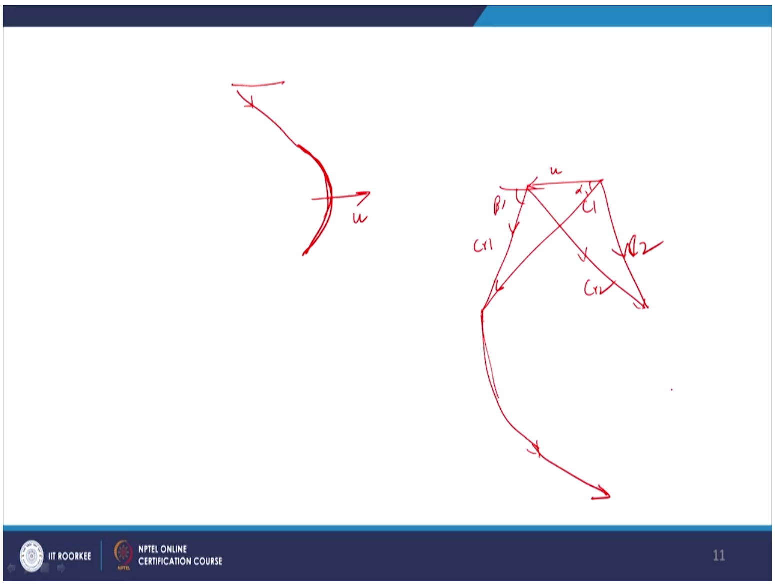

Now, in a steam turbine, when the steam enters the blade suppose there is a blade let us understand the velocity diagram; because we need velocity diagram if anyone to judge the output and the power from the steam turbine. So, steam turbine blade is moving with the velocity u in this direction.

So, a steam should glide over the blade surface right, a steam should glide over the blade surface already it is moving with it velocity u right. So, what should be the velocity of absolute velocity of the steam that is one thing right. So, we will draw simply draw the velocity diagram, suppose this is the velocity of blade u and steam is coming in this direction this is going to be the relative velocity.

So, blade should be like this it should glide over to the blade. So, blade has to be like this it should not be like this because in that case steam with there will be a axial thrust on the. If there axial thrust if there is axial thrust, then the turbine will start shaking it is totally undesired.

So, this is known as blade in that angle and this one is known as the nozzle is that angle right. And when leaving when leaving, it should leave here right. So, like this now this is suppose this is C 1 this is C r 1 this is u this is C r 2. Leaving from this side right it is again allow the curvature of the blade and then we get this is the absolute velocity C 2; this is the absolute velocity of the steam which is leaving those (Refer Time: 29:37) so, this is velocity.

So, for any rotor dynamic machine, whether it is a steam turbine or a gas turbine in or a axial flow turbine radial flow turbine velocity gram diagram has to be prepared. And this velocity diagram helps in designing the turbine and helps in finding out the different things like what is the output of the turbine right. So, so with this I conclude this lecture.

Thank you very much.