Steam and Gas Power Systems
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Module No # 08
Lecture No # 40
Problem Solving

I welcome you all in this course on steam and gas power systems based on this section we will solve a few problems based on this course starting from steam power systems.

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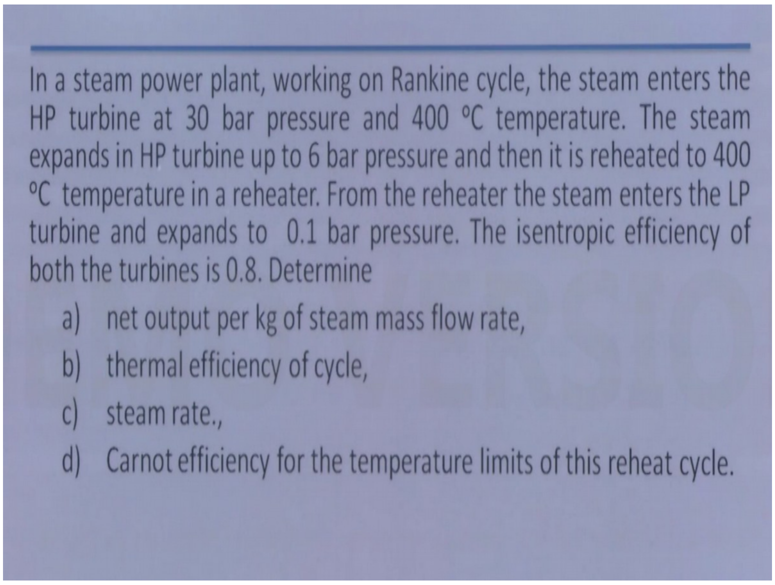
In a steam power plant, working on Rankine cycle, the steam enters the HP turbine at 30 bar pressure and 400 °C temperature. The steam expands in HP turbine up to 6 bar pressure and then it is reheated to 400 °C temperature in a reheater. From the reheater the steam enters the LP turbine and expands to 0.1 bar pressure. The isentropic efficiency of both the turbines is 0.8. Determine

a) net output per kg of steam mass flow rate,
b) thermal efficiency of cycle,
c) steam rate.,
d) Carnot efficiency for the temperature limits of this reheat cycle.

So the first problem (())(00:30) with the steam power system based on modified rankine cycle in the steam power plant working on rankine cycle steam enters the HP turbine at the 30 bar and pressure 400 degree centigrade.

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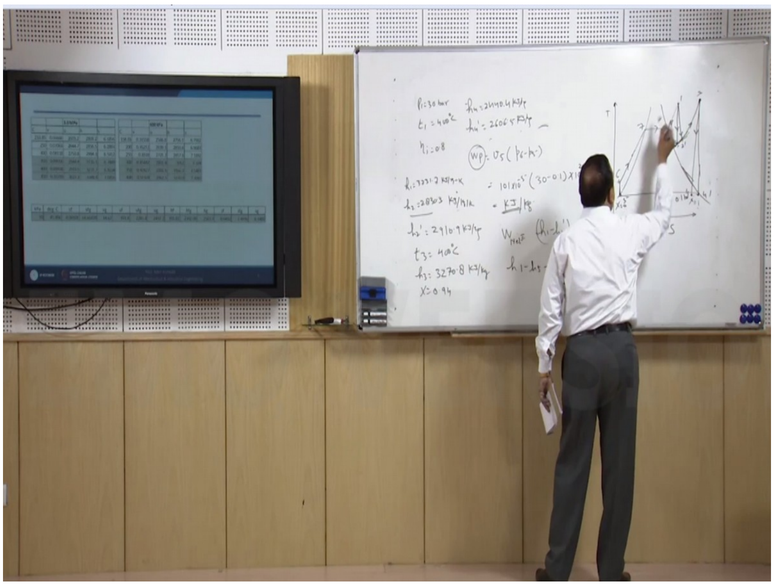

So there is a steam power plant in this power plant we will draw the processes on temperature entropy diagram which is quality zero this is quality one the steam enters the HP turbine at 330 bar pressure 400 degree centigrade temperature. So 30 bar 400 degree centigrade the steam enters the turbine right.

So P1 is 30 bar then T1 is 400 degree centigrade the steam expands in HP turbine up to 6 bar pressure and then it is reheated to 400 degree centigrade again. So that temperature is restored in the re-heater from the re-heater the steam enters the low pressure turbine and expands to 0.1 bar pressure the isotropic efficiencies of both the turbine is 0.8.

Isotropic efficiency of both the turbine is 0.8 now the issue is definitely first of all let us find out the state of steam at 30 bar pressure and 400 degree centigrade temperature. If we look at this steam table this is 30 bar is 3 mega Pascal. So three mega Pascal pressure the saturation temperature is 200 and 33.84 degree centigrade

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		3.0 MPa		
C	v	u	h	s
233.85	0.06666	2603.2	2803.2	6.1856
250	0.07063	2644.7	2856.5	6.2893
300	0.08118	2750.8	2994.3	6.5412
350	0.09056	2844.4	3116.1	6.7449
400	0.09938	2933.5	3231.7	6.9234
450	0.10789	3021.2	3344.8	7.0856

		600 kPa		
C	v	u	h	s
158.83	0.31558	2566.8	2756.1	6.7592
200	0.35212	2639.3	2850.6	6.9683
250	0.3939	2721.2	2957.6	7.1832
300	0.43442	2801.4	3062	7.374
350	0.47427	2881.6	3166.1	7.5481
400	0.51374	2962.5	3270.8	7.7097

kPa	deg. C	vf	vfg	vg	uf	ufg	ug	hf	hfg	hg	sf	sfg	sg
10	45.806	0.00101	14.66899	14.67	191.8	2245.4	2437.2	191.81	2392.09	2583.9	0.6492	7.4996	8.1488

It means the steam is super heated now super heated steam at 400 degree centigrade the enthalpy of steam is 2933.5 this is enthalpy is 3200 and 31.7 kilo joules per kg right. So H1 is 3231.7 kilo joules per kg and T1 is already given. So it is a super heated steam now entropy because the expand is expansion is isotropic posses.

So the entropy at this stage is 400 and 6.9234 kilo joules per KG Kelvin right. So we have state fix now isotropic expansion is taking place up to 6 bar state2 6 bar so at 6 bar entropy is going to remain constant so let us look at the properties at 6 bar that is 6 kilo Pascal the entropy constant entropy. So when the entropy is remaining constant it is saturation saturated from the entropy 6.7592.

It means at 6 bar the steam is super heated right and through cos interpretation because at 400 degree centigrade. It is 7.7 so 6.92 will lie between these two two hundred degree and 153 degree so linear interpretation will be done and then we will get the value of S2. S2 = 6.9233 = SF + X SFG right similar time of numerical.

We have solved similar type of numerical with the respective lecture related with the vapour power cycles from here we will get the value of X right now H2 i have done the cos interpretation. Now H2 is 2830.3 kilo joules per kg right and X we cannot calculate for because this is already super heated. So this is this cannot be done. So vapour is super heated at state one it is expanded to state 2.

Right at state 2 it appears to be super heated and it is super heated because the entropy is 6.7592 and here entropy is 6.923232. So it is super heated and to linear interpretation we have calculated the value of H2 S. So H1 is 323.7 and H1 is 28303 kilo joules per kg Kelvin.

But this is not an isotropic process in action. It is processing like this is two dash right and this falling on this line. So H2 dash then again H2 dash - H1 divided by H2 - sorry H1 - H2 dash divided by H1 – H2 = efficiency isotropic efficiency of turbine it is already given. So it is isotopic efficiency is already given we have the values of H1 and H2 as well.

So H2 dash can be calculated from here and H2 dash is 2910.9 kilo joules per Kg now this super heated vapour is reheated up to stage three and that is again at 400 degree centigrade. So T3 is 400 degree centigrade. So from here the properties of super-heated vapor at 400 degree centigrade we can get the value of enthalpy.

So H3 is 3270.8 kilo joules per kg this is enthalpy at state three now again steam is expanding and it is going up to 0.1 bar now entropy at state three S three is it is kilopascal 400 it is 7.7097 kilo joules per kg now entropy of at .1 bar this is 10 kilo Pascal the entropy is 8.1488.

It means the vapour is the quality of vapour is less than one so you will take S3 is equal to this is let us say this is 1 SF4 + X SFG4 now entropy starting from here entropy at state 3 = entropy at state 4 because saturated vapour the entropy or saturated vapour at state 4 is higher than that entropy at state 3 that is why it the vapour available at state 4 is does not have quality is equal to 1 it is quality less than 1.

So iam repeating the steps first of all we have taken the steam super heated steam at state one properties are taken from the steam table at 400 degree centigrade temperature and 30 bar steam is expanded to 6 bar we have compared the properties and we have found that at 6 bar also or 600 kilo Pascal also or the steam is superheated right while even interpolation from the steam.

We have calculated the enthalpy at state two efficiencies given we have calculated the enthalpy at state two dash because efficiency is .9 then again it is reheated to state three which is at 400 degree centigrade. So those properties are also taken from the steam table for the super heated vapour at 600 kilo pa square then steam is expanded in the low pressure turbine and at the exit the pressure is .1 bar.

And now we have compared the entropies and we have found that the quality is less than one so we have we are going to use this equation now S3 we have taken from here SF4 and SFG4 S4 and SFG4 shall be taken from the steam table and after manipulation the value of quality is 0.94. So X = 0.94 that is the quality of vapour at this state. Once we have the quality of vapour at this state.

Then we can find the H4 is HF4 + X HFG4 right and using this equation when we calculate the value of H4 then we get the value of H4 is 2440.4 kilo joules per kg but this passes is also not isotropic right so we get another state four dash this is four right and for four dash again isotropic efficiency is H3 - H4 dash divided by H3 - H4 now from here we get the enthalpy at 4 dash.

So H4 dash is 266206.5 kilo joules per kg. Right now we have enthalpies at all the same points now this vapour is then available at the exit of the turbine .It is condensed fully condensed then we get five then pressurised and then it goes to the boiler and then like this so it is 5, 6, 7 and then 1 this is 8 and then 1.

So feed water goes to the boiler at pressure six at state six heat is added here up to state 1 expansion in high pressure turbine then again reheat then again expansion at low pressure turbine and then condensation in condenser. Now work of a pump is equal to a specific volume of the pump with the specific volume at of the pump specific volume at state 5 state volume and P6 – P5, P5 is 01 bar P6 is 30 bar.

So it is 101 into 10 to power - 5 and 30 – 0.1 into 10 to power 2 then is that is in kilo joules of per kg input given by the pump that is VDP. So this is given in bar we have converted into the kilo joules sorry kilo Pascal this pressure in bar is converted into the pressure in kilo Pascal and then we have calculated the work of the pump.

Now work of the turbine = H1 – H2 dash + H3 – H4 dash this is because we are getting work output from here and work output from here net output is because this part of the energy is used for running the pump. So this will be minus work of the pump will be the net output of from this is system from the cycle output of the turbines minus energy consumed by the pump.

Now heat supplied during this process ids equal to now we do it know the enthalpy at state 6 but we have a enthalpy of state 5 that is enthalpy of saturated liquid at .5 bar that is HF 191.8 one so if in this enthalpy. We had the pump work we will get enthalpy of a state 6 or what we can do H1 - H5 that is enthalpy difference between this and this and we will add the pump work.

Then we will get enthalpy at state six because now after calculating the net output we have to calculate how much heat is given in the system. So the heat is given in the cycle is H1 - H6 but we do not have the enthalpy at H6 because H6 fluid is compressed liquid right. But we have enthalpy at state 5 this enthalpy at state 5 is nothing but the enthalpy of the liquid HF 191.81 ok.

So heat added during this process H6 to H1 we can take H1 – H5 this is enthalpy this minus enthalpy this plus sorry minus work consumed by the pump because this is not this heat energy is not added in the boiler so minus work PF the pump. So that is the net heat added from state 1 to state 6 plus heat added during state 3 to state 2 dash because it is a reheat cycle + H3- H2 dash this is the net amount of heat added in the cycle.

So here in this question we have to find the net output per kg of a steam mass florate. So net output we are getting from here from this equation all the values are known to us right thermal efficiency of the cycle will take the ratio net output divided by the heat supplied will give the thermal efficiency of the cycle. Now third one is the steam rate the steam rate is 3600 divided by W the output and this will be in kg per kilo watt hour right and next is carnot efficiency for the temperature limits of the reheat cycle.

So carnot efficiency the minimum temperature is this maximum temperature is this so we can always calculate the carnot efficiency of the cycle right. Now after this we will take another numerical on gas turbines. Now we will quickly we will go through the steps to solve this numerical now this numerical has two state compression it is the gas turbine is equipped with intercooling regeneration and reheat arrangements ok.

So a gas turbine is equipped with intercooling regeneration and reheat arrangement the HP turbine is used to drive the compressor and LB turbine gives the output. So there are two turbines one is driving the compressor and another is giving the output the exhaust pressure of LP turbine is one bar and the turbine inlet temperature for both the turbine is thousand twenty Kelvin

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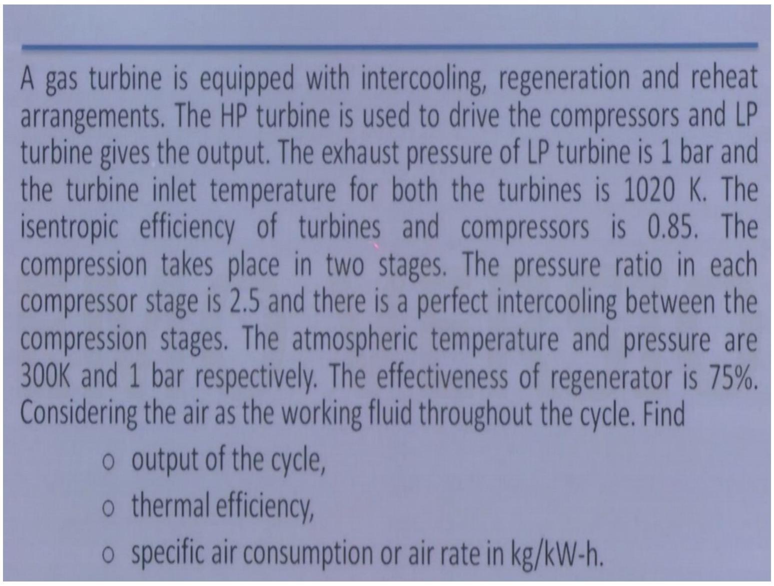

The isotropic efficiency of turbine in compressors is 0.85 the compression takes place in two stages. So there are two compressors and two turbines right. The atmospheric pressure sorry atmospheric temperature and pressure are 300 Kelvin and one bar respectively the effectiveness of regeneration is 75% consider the air as a working fluid throughout the cycle.

Find the following output of the cycle thermal efficiency is specific air consumption in kg per kilo watt hour.

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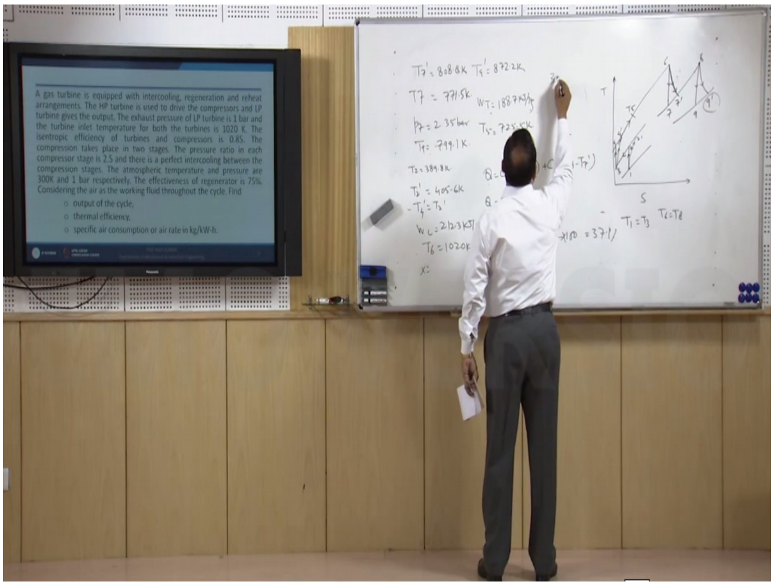

So it is a cycle which is drawn on temperature entropy diagram it has two stage compression it is so 1 to 2 and it has certain isotropic efficiency 2 dash then cooling after cooling again it is 3 and then this is 3 dash. So first compression and then intetrcooling and then again compression then in the compression chamber the two turbines.

T six and then expension is high pressure turbine then we get T6 to 7, state7 to then again state temperature at 6 is equal to temperature at 8 then again expansion and we get state 9 and this is 9 dash. So compression then cooling because there is a perfect intercooling when T1 = T3 and then heat edition expansion in turbine and then again reheating and T6 = T8.

It is given in the problem statement then expansion in high pressure turbine and low pressure turbine this is the arrangement. Now here again first of all we will calculate the value of T2 = T1 raise to power P2 by P1 raise to power sorry P1 multiplied by P2 and P1 raise to power gamma - 1 more gamma now P1 is three hundred and P2 is 2.5 pressure in each temperature is 2.5 raise to power .286 and this will give 389.8 Kelvin.

So T2 is 389.8 Kelvin right now similarly we will calculate the T2 dash sorry T2 dash and in order to calculate T2 dash again the efficiency = T2 – T1 divided by T2 dash - T1 here we have the value of T2 and T1 as well and efficiency is also with us right we are using these values. We will get the T2 dash as 405.6 Kelvin.

Now we need not calculate the value of T3 and T3 dash because T2 dash is going to be because polytrophic efficiency is same. So T2 dash is going to T3 dash and T1 = T3. So T 3 dash is also =T2 dash ok sorry this is not 3 this is 3 this is 4. 4 is not 3 this is 4 this is 4 dash so T4 dash. So we need not calculate the value of 4 or 4 dash.

So T 4 =T2 and T4 dash = T2 dash now work of the compressor is equal to first the CP T2 dash - T1 because there is a perfect intercooling work in both the work consumed by the both the compressor is same. So we can always multiply it by 2 T2 dash and T1 when we are putting the values we are getting the work of the compressor as 212.3 kilo joules per kg. Now the work of the compressor with us.

Now these compressors are run with the high pressure turbine as per the statement of the problem. The HP turbine is used to drive compressors and LP turbine gives the output it means CP T6 –T7 = 212.3. Right and T2 we have with us 1020 Kelvin .So T6 is where as we can calculate the value of T7 and T7 is sorry here there is a correction instead of T6 it is T7 dash because the power is developed in this process.

So it is going to be T seven dash right. So CP T6 – T7 dash now from here we will get the value of T7 dash once and that is equal to 808.8 Kelvin now once we have the value of T seven dash we can calculate the value of T7 it is T6 – T7 dash divided by T6 – T7 efficiency of the turbine is 0.85 T6 is we have already kept it is given in the problem statement T7 dash.

We have calculated right. Now we can calculate the value of T7 now the T7 is 771.1 Kelvin sorry this is 71.5 Kelvin we have already we are having now we are having the value of T7 now we are having the value of T6 we are also having the value of P6 now we can get the value of T7 so T6 by T7 = P6 by P7 raise to power gamma -1 gamma.

From here we will get the value of P7 now the P7 is 2.35 bar right now P7 is same as P8 it is the constant pressure process now we have the value of T8 and P8 now we can find the value of T9 = T8 1 bar exhaust pressure is 1 bar. So one bar or we can write p nine by P8 raise to power gamma -1 over gamma.

So this is one bar and P8 is 10201 by P8 is P7 2.35, 0.286 and this will give the value of temperature at state 9 and this is 799.1 Kelvin again w have the efficiency of this .85 and we can calculate the value of T9 dash and T9 dash is 872.2 Kelvin right now we have temperatures at all salient states or salient points.

Now work of the turbine = CP T8 – T9 dash during this process CP for here we know that is 1.005 – 832.2 and this work of the turbine = 188.7 kilo joules per kg right now with the exhaust of this heating of the gas which is coming from the compressor is done.

Right the gas available is at T9 dash and compressor outlet is T4 dash and suppose it is heated up to T5 right. So actually transfer is T5 - T4 dash multiplied by CP divided by maximum possible heat transfer that is T9 dash - T4 dash into CP and that is equal to how much effectiveness is 75%, 0.75 now from here we will get the value of T5 because T4 dash is with us T9.

We have already calculated T4 dash CP will be cancelled .75 is given. So from here we will get the value of T5 and T5 is 725.5 Kelvin right now heat added in the cycle now heat added is Q now heat added is enthalpy at 6 - enthalpy at 5. So Q is CP T6 – T5 + CP T8 – T7 dash. We have temperatures at all these points CP.

We can take from here and now we get the value of Q is 508.1 kilo joules per kg because in the entire cycle heat is added at two places here and here and this much heat is coming from the exhaust gases right. Now we have the value of Q thermal efficiency is going to be the output of this turbine divided by Q because this output of the turbine is used to run the compressor.

So it is going to be 188.7 divided by 508.1 into 100 and this is going to be 37.1% and the specific air consumption is nothing but 3600 divided by work of the turbine 188.7 and that is going to be equal to 19.08 kg per kilo watt hour now after this we will quickly go for this numerical.

This is very interesting numerical on the leakage in or losses in steam turbines in this numerical it is stated that the calculate the leakage loss through diaphragm packing in a turbine under the following conditions steam pressure before nozzle a steam so we have to calculate the leakage through the diaphragm in the diaphragm the nozzles are fixed the steam pressure before nozzle.

50 bar a steam super heat 55 degree centigrade steam pressure after nozzle is given shaft diameter is given radial clearance.

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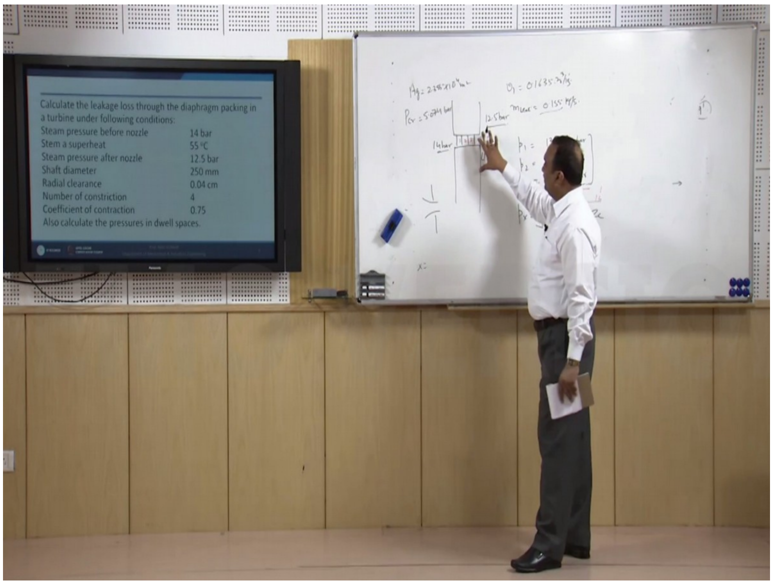

So the leakage will take place through radial clearance right and there are constrictions i will draw in larger figure there constrictions provided here and number of constrictions is four so four constrictions are provided. So it means dwell spaces are three this side pressure is 14 bar now we have to calculate how much a steam will leak through constrictions clearance is also given here.

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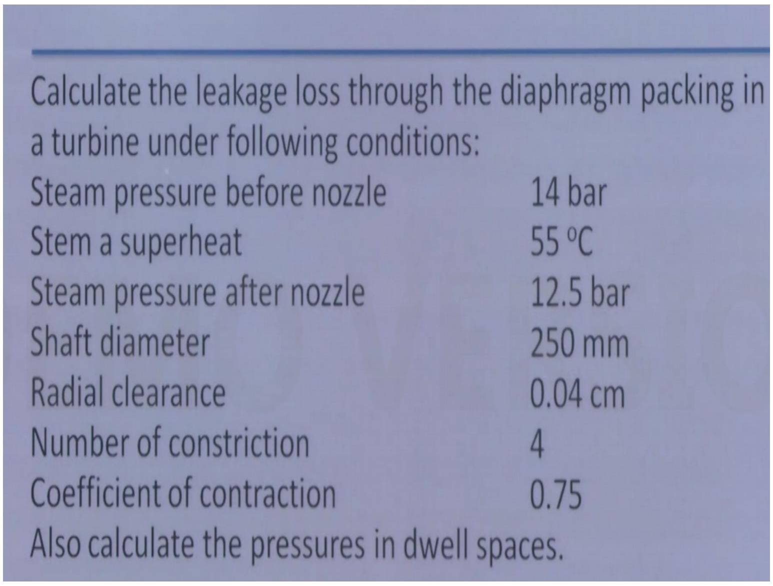

Radial clearance is 0.04 centimetres around 400 microns right .So first of all from the steak table TS corresponding saturation temperature corresponding to 14 bar. So TS = 195.04

degree centigrade this is the saturation temperature from the steam table but the steam is super heated by 55 degree centigrade.

So degree of super heat this is 55 degree centigrade is degree of super heat. So we will add 55 here so temperature of the steam is 250.04 degree centigrade. Now area of constriction Ag. Now Ag is Cc pie D and this is clearance right this is constriction coefficient because when there is a flow in sudden obstruction or sudden construction cons construction or enlargement vena contractor is formed.

So that has been taken account here in Cc right so it is zero point coefficient of contraction 0.75 into pie into diameter is 250. So it is 0.25 into 0.04 into 10 to power -2 and that is the area right and this is Ag is we will write here. Ag is 2.355 into 10 to power - 4 meter in square second thing we have to see on the (()) (35:55) side the pressure is greater than critical pressure or less than critical pressure because in both the cases the analysis will be different.

So on this side (()) (36:07) side the critical pressure is 0.85 P1 under root ZC + 1.5 here ZC is number of constriction they are four and P1 is 14 bar right and now from here we get the P critical as 5.074 bar.

Now this critical pressure is less than the pressure at that side this is 12.5 bar it means on the other side the pressure is not less than the critical pressure it is above the critical pressure once on the other side the pressure is above the critical pressure the leakage through the constriction will be mass leak is going to be Ag under root P1 square – P2 square divided by ZP1 V1 now e have the value of P1 4 bar P2.

How much 12.5 bar will convert them into kilo pascal right and then Z P1 this is P1 same Z P1 and is specific volume so specific volume of a steam super heated steam w have taken from the steam table as 0.1635 metre cube per kg. So initially we had a steam which is super-heated by 55 degree centigrade.

So we have taken the specific volume of that steam right from the steam table that is this specific volume initial pressure is known that is 14 bar and pressure on the other side is 12.5 bar and this will give the leakage as mass of a leakage as 0.155 kg per second so this is the leakage this is the amount of leakage taking place through these constrictions.

Now it has three dwells and dwell spaces number of dwell spaces is three and M = AG under root P1 square - PX square divided by ZC P1 V1 tk now here leakage is because it is moving in this direction. So the leakage is same 0.155 T1 is 14 bar this is 14 bar right now ZC we have to see now P1 is again 14 bar PX.

We have to calculate i think also calculate the pressures in dwell spaces so dwell space pressure dwell space one pressure dwell space two pressure in dwell space three so this we have to calculate rest of the information is with us and if we put the values we get the value for PX as under root 196 - 9.915 ZC when you put ZC = 1 we get the value of P XI will write here when ZC = 1 then or we can P1 = 13.64.

When we put this = 2 then we get P2 = 13.27 and when we put this is = 3 we get P3 as 12.98 bar they are all bar right and beyond that there is a pressure of 12.5 bar. So this is how we can calculate for this information have designing the seals for steam turbines. Ok this was the last lecture i wish all of you best of luck for the coming examination of this course thank you very much.