Steam and Gas Power Systems
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Module No # 07
Lecture No # 34
Problem Solving (Gas Turbine Cycle)

Hello I welcome you all in this course on steam and gas power systems and this session will solve certain numericals.

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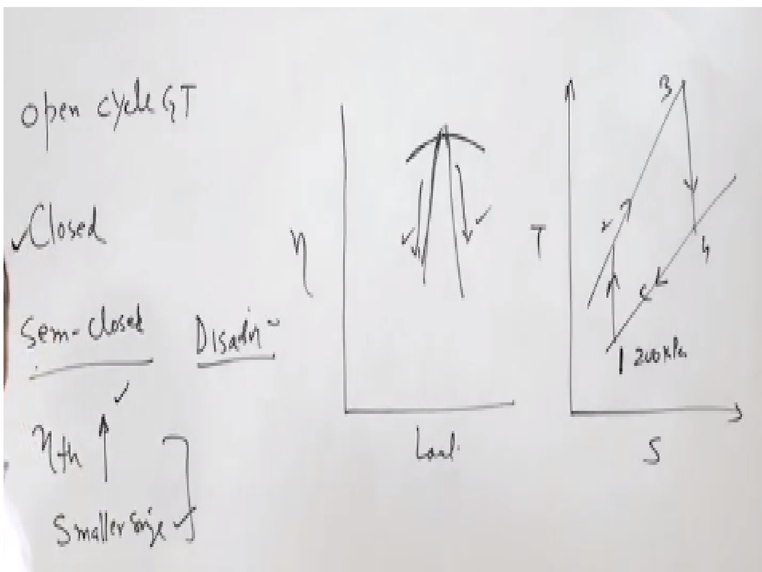

But before start solving numerical I must tell you that the gas turbines are we simply discuss the open gas turbines rankine cycle gas turbines. There are closed cycle gas turbines also and there are semi closed type also or semi open.

Now in open type of gas turbine the compressor sucks air from the surroundings and this air participates in combustion in the combustion chamber hot flue gases emerging from the combustion chamber they go to the turbine expansion takes place output is attained and exhaust of the turbine is sent to the atmosphere or used for regeneration.

In close cycle gas turbine the entire circuit is closed it means if we start from this temperature entropy diagram state 1 to three and four the entire cycle is closed cycle no fresh air is suck into the system in the combustion chamber the air is used other than the air in the cycle outside is used for burning the fuel in this case in such type of system we can use low grade type of fuel also and the entire system can work on relatively high pressure this pressure at stage 1 need to be specific pressure it can be let us say 2 bar or 200 kilopascal.

So the entire cycle will shift in upward direction and it is going to be for the same output we can have a compact cycle it has a certain advantages and disadvantages. First advantage is because the cycle can operate on high pressure side so the thermal efficiency is high or we can design a cycle for high thermal efficiency when thermal efficiency is high it means for the same power output the size of the plant will reduce the smaller size eight we can say thermal efficiency is high if we are maintaining the same output then we can go for a smaller turbine.

For this close cycle gas turbine part load efficiency is also very good I mean it is better than the open cycle gas turbine. If you compare the part load efficiency it is a efficiency and the load every power generating machine (())(3:18) is designed for a particular route right at a particular load efficiency may be high but the moment you change the load efficiency may not the reduction or in efficiency may not be significant right.

But in turbo machines this happens with the (()) (03:40) machines like IC engines 2 stroke or four stroke engines but in turbo machines this curve is like this it is almost vertical. So that the moment you deviate from the design condition the detoriation in the efficiency is very fast but if you compare the this known as design performance but if you compare the but if you compare the off design performance of flow cycle gas turbine and open gas turbine.

The off design performance of low cycle gas turbine is greater than that of total cycle gas turbine and in because the cycle is close. So working medium is not lost there is no loss in working medium right for burning in the burning the flue in the combustion chamber external air is used (()) (04:26) number is high. In during the cycle right and in this cycle no contamination takes place.

So due to contamination loss in energy due to contamination that is also avoided in closed cycle in the closed cycle in gas turbines and of course we can use expensive fuel for flow cycle gas turbines they are certain disadvantages also disadvantages it is a dependent system because cooling from process state 1 four to state 1 has to be d1 in a condenser.

So it is a dependent system it is I mean it is a complex system also it is not as simple as the open cycle gas turbine it is a complex system and cost wise also cost of low cycle gas turbines is high right.

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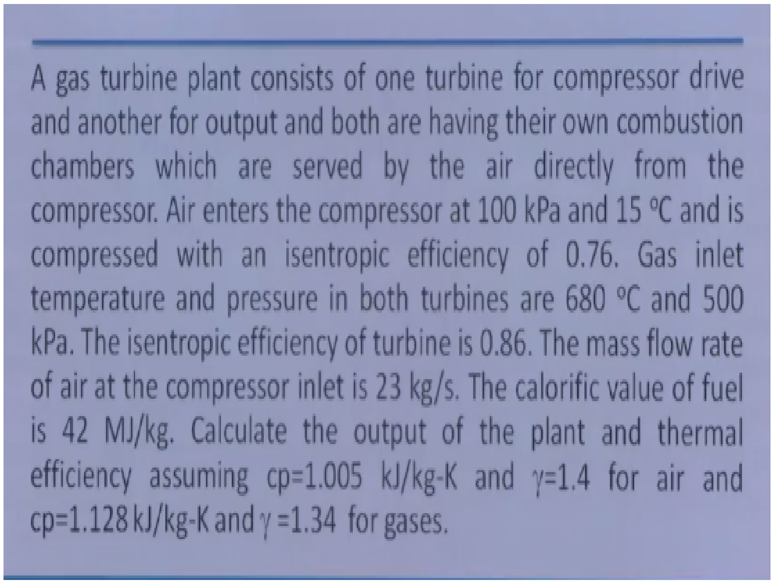

Now after this we will solve certain numerical on gas turbines this is the first one which states that a gas turbine plant consist of 1 turbine per compressor drive and another for output both are having their own combustion chamber which are served by air directly from compressor. Air enters the compressor at 100 kilopascal and 15 degree centigrade and its compressed with the isentropic efficiency 0.76.

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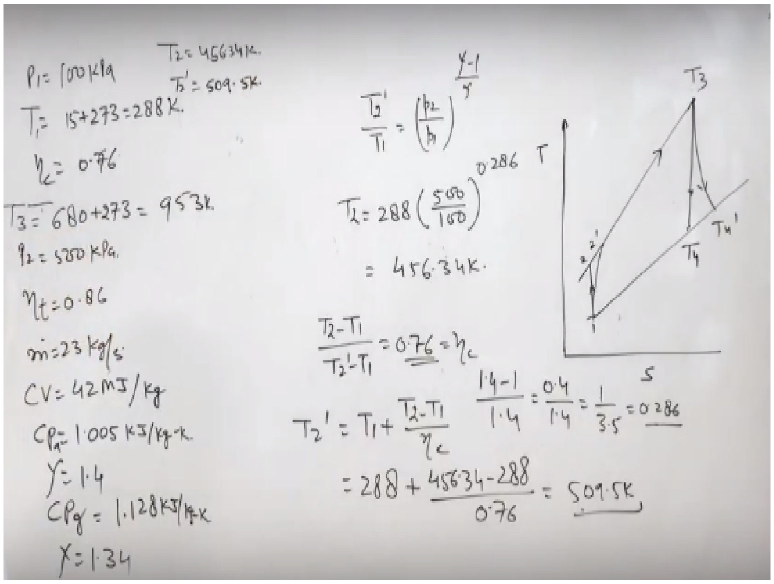

So we start let us start drawing the temperature cycle on temperature entropy diagram so state 1 to state 2 and it has certain isentropic efficiency. So definitely the compression is not isentropic so we will be getting 2 dash air enters the compressor at 100 kilopascal. So P1 = here we will write 100 kilopascal and T1 is 15 so 15 + 273 288 kelvin.

Isentropic efficiency is 0.76 gas inlet temperature and pressure both turbines are 680 degree centigrade. So this is gas inlet temperature this is T3 and T3 is 680 degree centigrade + 273 is going to be 3953 kelvin or to write here T3 = 680 + 273 = 953 kelvin.

And 500 kilopascal so P2 is 500 kilopascal the isentropic efficiency of the turbine is 86 % so isentropic of is 0.86 this is isentropic efficiency of the compressor. The mass flow rate of the air at the compressor inlet is 23 KG per second mass flow rate is 23 KG per second. The calorific value of fuel is 42 mega joules per KG.

So CV is 42 mega joules per KG calculate the output of the plant and thermal efficiency as assuming CP and air CP = 1.005 kilo joules per KG kelvin and gamma is 1.4 for air is CP for gas is different so this is CP for air CP for gas is 1.128 kilojoules per KG kelvin and gamma is 1.34 so these are the data cycle is this and the particular thing about this numerical is that it has 2 turbines both are having their own combustion chamber which are served by the air directly from the compressor.

So compressor air is divided into two parts it goes into two different combustion chambers and combustion takes place the gas inlet temperature and pressure in both turbines is also same. So we will start with finding out the temperature at salient points P4 because it has also certain efficiency this is T4 dash. So the numerical are related with the gas turbines first thing you should do you should try to find temperatures at all the places.

Once we have the values of temperatures if specific heat is normally given if the numerical they specific heat of the gas is not given you can take the specific heat of the air and that is how you can find the total energy or enthalpy in that place and enthalpy difference can be calculated right. So first of all because we will find the temperature of air at state 2 so 2 dash T sorry T2 by T1 = P2 by P1 raise to power gamma - 1 over gamma.

So gamma is 1.4 so gamma - 1 by 4 gamma 1. and 4 – 1.4 it is 0.4 by 1 by 1.4, 1.3, 1.5 0.286 so directly we can use 0.286 instead of writing this. So T2 = T1 is 288 P2 by P1 now P2 is 500 T1 is 100 raise to power 0.286 and this case value of T2 as 456.34 kelvin right.

Now once we have the value of T2 T2 we can write here T2 = 456.34 kelvin again once we have the value of T2 then T2 - T1 divide by T2 dash - T1 = efficiency 0.76.

Now T2 dash = T1 + T2 - T1 divided by efficiency of this 0.76 this is efficiency of the compressor right and then is T1 is 288 + T2 is we have calculated 456.34 - 288 divide by 0.76 and this gives the value of T2 dash as 509.5 kelvin. So T2 dash = 509.5 kelvin now we have value of T2 we have value of T2 dash.

Now T3 is 953 kelvin it is already with us now T3 is with us we can easily find the value of T4 because all these values will be required later on.

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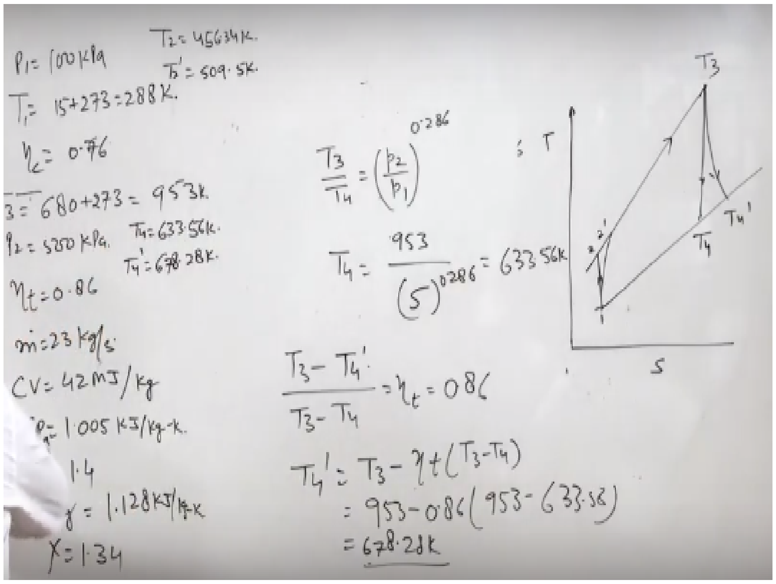

So T4 T3 by T4 = P4 by P1 raise to power 0.286 instead of writing gamma - 1 over gamma and rating .086. Now T4 is T3 divided by P2 by P1 T3 = how much 953 so we will directly write 953 kelvin and P2 by P1 is 500 by 100 raise to power 0.86 and this gives the values of T4 as 633.56 kelvin.

So T3 T4 633.56 kelvin ok now T4 dash so T4 dash sorry T3 - T4 dash divide by T3 - T4 is efficiency of turbine efficiency of turbine is given here it is 0.86. So T4 dash = T3 - efficiency of the turbine T3 - T4 and that is T3 is 953 kelvin. So 953 – 0.86, 953 - T4 is 633.56 and this gives the value of T4 dash is 678.28 kelvin.

So T3, T4, T4 dash is 668.2 eight kelvin now we have temperatures at all salient points right. Now after this we will calculate work consumed by the compressor because compressor is providing air for both the turbines and each turbine is having its own combustion chamber.

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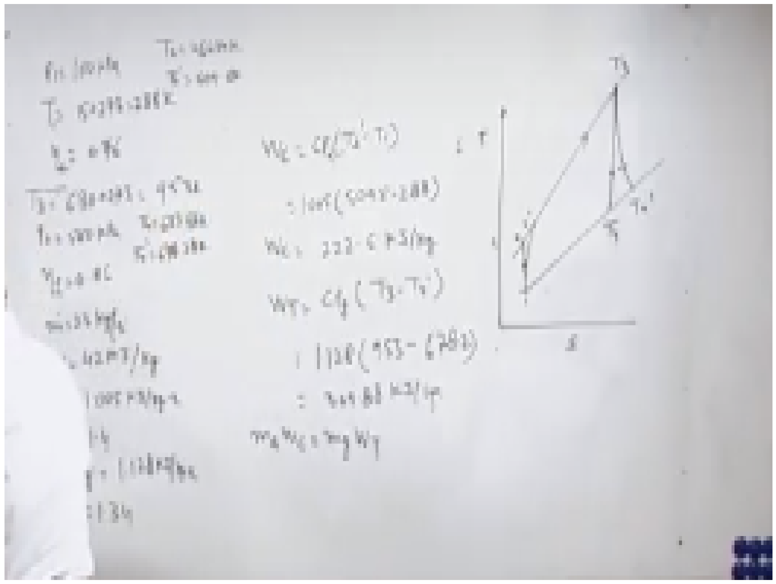

So work of the compressor is CP T2 dash - T1 right now T2 dash is 509.5. So 1.005, 509.9 - T1 is 288 right. So work of the compressor is 222.6 kilo joules per KG this is work of the compressor. Now work of the turbine each turbine because both are the turbines are having the maximum temperature right.

So work of per KG per KG work for each turbine is same if you change the mass flow rate then definitely we are going to have different work output. So per KG of gas work output is turbine is CPG this is CPA T3 - T4 dash. CDG is given here 1.128 T3 is hmm 953 and T4 dash is right 678.2 and then work of the turbine is 309. 88 kilo joules per KG.

Now this turbine is used for running this compressor so this is specific work output mass of the air in compressor = mass of the gas multiplied by mass work of the turbine.

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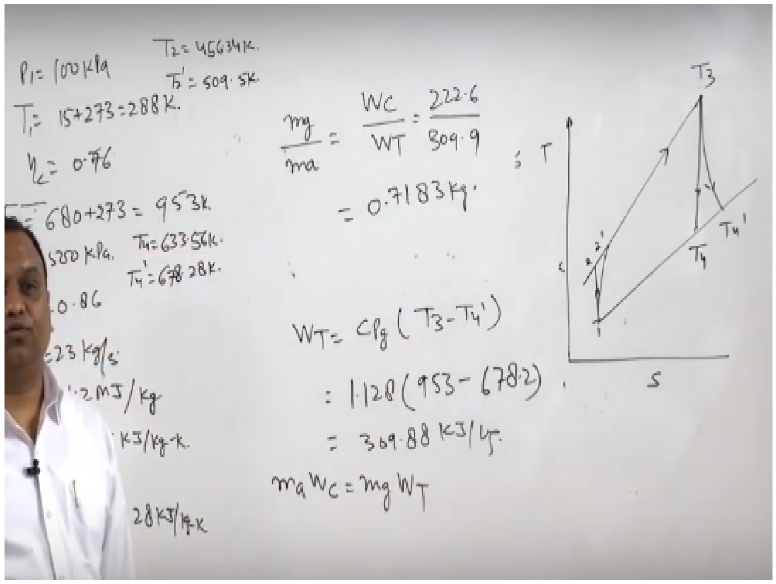

Now if we have to find the ratio of gases gas and air then mass of the gas divide by mass of the air right = hmm work of the compressor divide by work of the turbine. Work of the compressor we already calculated 222.6 kilo joules per KG right work of the turbine is 309.88 or 309.9. So the ratio of mass of the gas and mass of the air is 0.7183 KG.

It means this ratio is existing for so if we are using now it means 1 KG of air which is sucked into the compressor is burned in the combustion chamber right some mass of the fuel is added suppose X mass of fuel is added. So 1 + X out of that this much of flue gases are used in 1 turbine to meet the energy expand spent energy spent in compressing the gas.

Now this 1 KG of air and X KG of fuel - this will give the output will be used for output turbine not give the output it will give for output turbine.

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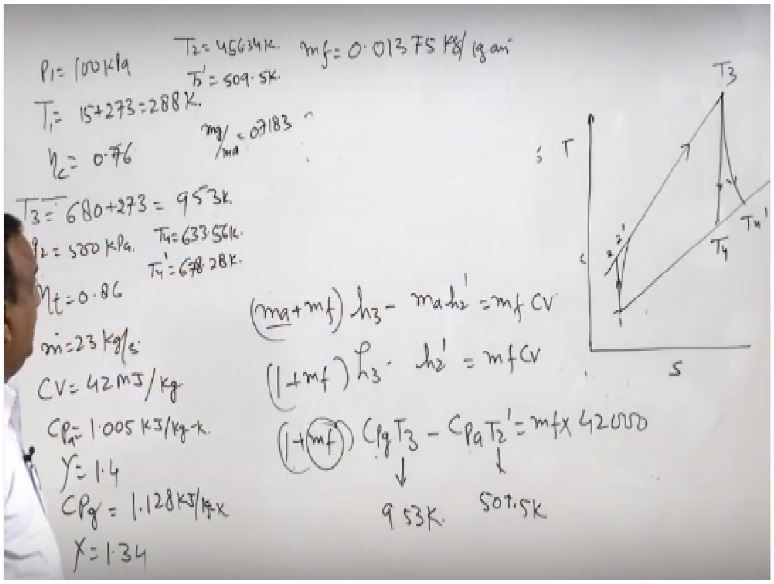

So now vertical we can write so this NG by NA will write somewhere NG by NA = 0.7183 because we will be requiring this formation later on. Now NA + NF mass of the air + mas of fuel burnt here H3 - NA H2 dash combined in for the turbines we have considered this NF for both the combustion chambers right = mass of the fuel into calorific value of the fuel right.

And if you are KG using add is 1 because we want find how much fuel is burnt for 1 KG of air. So if we take 1 KG of air then MF H3 - H2 dash = MF CV right now H3 again 1 + MF CPG P3 - CPA T2 dash = MF into 42000 because the calorific value is given in mega joules. So this mega joules it has to be converted into the kilo joules because we are dealing in Kilo joules.

Now T3 is with us T3 is 953 kelvin CPG is also with us 1.128 CPA specific heat of air is 1 .005 T2 dash T2 dash we have already calculated 509.5 kelvin now only known is mass of fuel. So mass of the fuel we are getting here from here we will be getting the mass of the fuel as 0.0137 five KG of fuel per KG of air mass of fuel this much of mass of the fuel is used for 1 KG of air.

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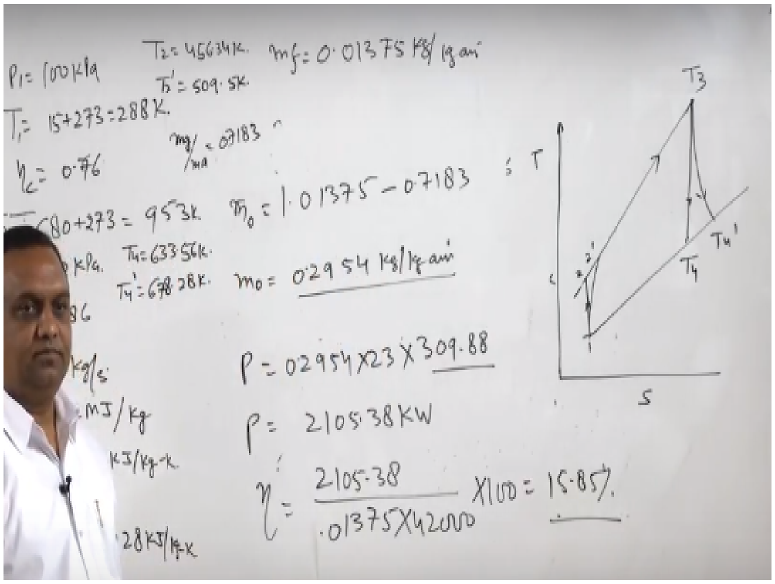

It means the total mass of the flue gases is total mass of the flue gases is 1 + MF that is 1 + 1.01375 this is the total mass KG per KG of air this is the total mass of the flue gases if we are compressing 1 KG of air right but out of this is used for running the turbine which is driving the compressor. So difference of these 2 mass of flue gases will be available for power generation.

So – 0.7183 will be used for output so MO = 0.2954 KG per KV of air is it clear. First of all here calculated how much mass of fuel will be burnt for 1 KG of air part of this flue gases this much is used for running the turbine which is driving the compressor rest of the flue gases will be used for power generation. So this is the amount of flue gases which are available for power generation when 1 KG of air is in circulation.

So power output is going to be 0.2954 now the mass of the air circulated in 23 KG per second into 23 into work output of the turbine. So work of the 2 turbine is 309.88 we have calculated earlier we have calculated earlier for work output of the turbine. So power output is 2105.38 kilo watt right.

And thermal efficiency thermal efficiency = power output 2105.38 divided by heat supplied. The heat supplied is 1.01375 this is mass of the fuel burnt here we will use only mass of the fuel burnt and calorific value of the fuel. This is the amount of heat liberated if we take this ratio multiplied by 100 and that will give 15.85 % that is the thermal efficiency of system ok.

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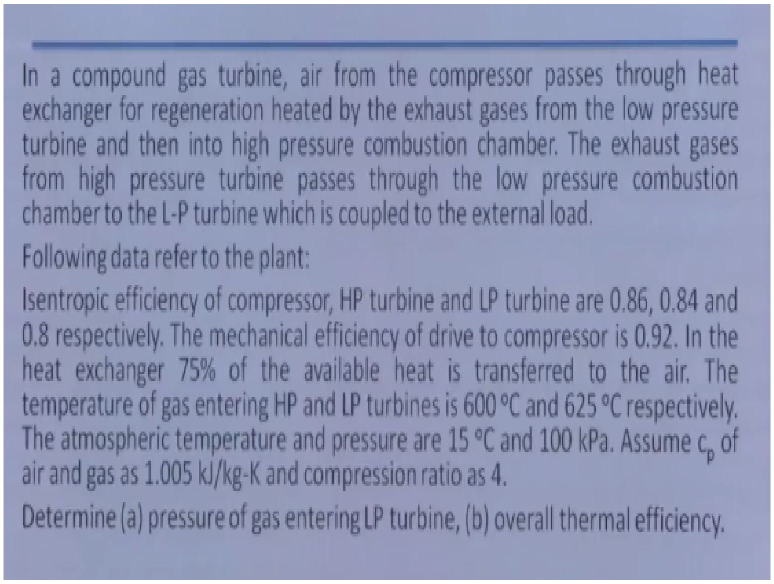

In a compound gas turbine, air from the compressor passes through heat exchanger for regeneration heated by the exhaust gases from the low pressure turbine and then into high pressure combustion chamber. The exhaust gases from high pressure turbine passes through the low pressure combustion chamber to the L-P turbine which is coupled to the external load.

Following data refer to the plant:

Isentropic efficiency of compressor, HP turbine and LP turbine are 0.86, 0.84 and 0.8 respectively. The mechanical efficiency of drive to compressor is 0.92. In the heat exchanger 75% of the available heat is transferred to the air. The temperature of gas entering HP and LP turbines is 600 °C and 625 °C respectively. The atmospheric temperature and pressure are 15 °C and 100 kPa. Assume c_p of air and gas as 1.005 kJ/kg-K and compression ratio as 4.

Determine (a) pressure of gas entering LP turbine, (b) overall thermal efficiency.

Now after this we will take up another numerical which is based on reheat cycle. Now reheat the problem statement that states in a compound gas turbine air from compressor passes through heat exchanger for regeneration heated by the exhaust gases from the low pressure turbine and then into high pressure combustion chamber.

The exhaust gases for high pressure turbine passes through a low pressure combustion chamber to low pressure turbine which is coupled to the external load means this problem there is reheat and regeneration right.

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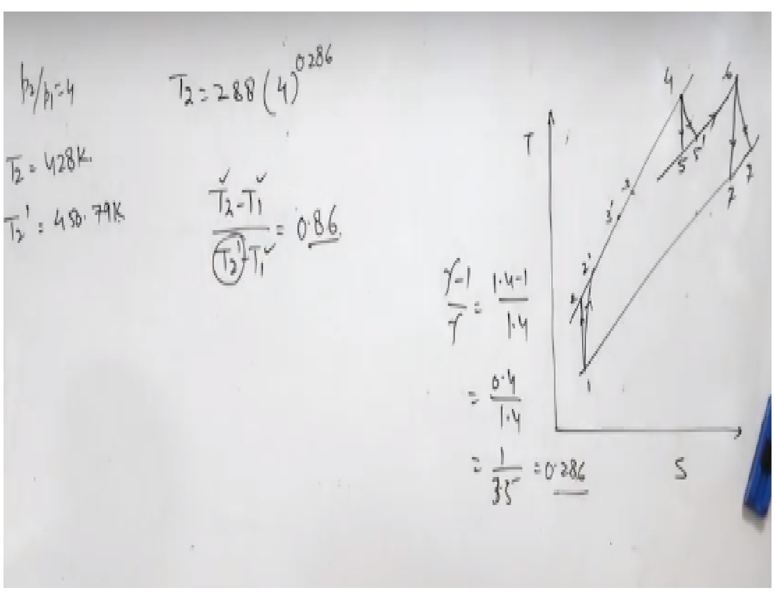

So if we draw the temperature entropy diagram for every problem this temperature entropy diagram has to be drawn. So now state 1 to state 2 and this efficiency also this HP and LP turbines are .86 and .84 and .8 respectively okay. So this has certain efficiency we will get 2 dash so isentropic efficiency of compressor HP turbine LP turbine are given .86, .84 and .8 respectively.

The mechanical efficiency is also given right so output will always multiplied by the mechanical efficiency that is the actual output will be getting right. So mechanical efficiency is the output available at rotor shaft divided by the output generated in the turbine. So turbine output and output available at the rotor shaft that ratio will give us the mechanical efficiency is .92.

In the heat exchanger 75% heat is available so effectiveness 75 % the temperature of gas entering HP and LP turbine is 6 and this temperature is different 6625 degree centigrade respectively. The atmospheric temperature in pressure 15 and 100 kilopascal CP for air and gas both are same compression ratio 4. So single compression ratio P2 by P1 = 4.

Now air is heated upto this .3 sorry this is three will get from regeneration so we will write 4. So it is 4 from 4 it is expanded to 5 again this is 5 dash the from 5 dash to 6 sorry 5 to 5 dash and then it is again reheated state 6 and 6 to 7 and then 7 dash ok. And after 7 this it should be heated upto three this is T3 state 3 but it is heated upto T3 dash only ideal temperature is 3.

If the regeneration is perfect this is regeneration has certain effectiveness it is it is only .75. So it will go upto three dash only now this is the temperature entropy diagram for entire process. Now first of all as we have d1 earlier in array numerical we will find the temperature at all the states.

So T2 quickly we will go for this T2 = 2 884 raise to power 0.286 here .286 is again gamma - 1 over gamma that is 1.4 - 1 divided by 1.4, .4 divided by 1.4, 1.3, .5 and 0.286 okay. So this gives T2 = 428 kelvin now again T2 - T1 divided by T2 dash - T1 = efficiency of the compressor is . 68.

Efficiency of the compressor is .86 right now T2 is with us T2 dash is not known from here we will get the T2 dash and the T2 dash is 450.79 kelvin of 450.8 kelvin right. And it is easy to do I mean we know the value of T2 we know the value of T1 and this is known to us and we can find the value of T2 dash.

Now 1 turbine is used for running the compressor so T4 - T5 dash CP right and it used to run the compressor CP T2 dash - T1. But here this is the turbine output and compressor is coupled with shaft so turbine output has now again it has mechanical efficiency of 92% .92. So this will be multiplied by mechanical efficiency so 0.9, 92, 1.0 because it is same for both the cases.

T4 is T4 is how much it is given here maximum temperature T4 is 600 degree centigrade so 873 kelvin - P5 dash = 1.005 multiplied by T2 dash is 450.79 - 288 from here we will get the value of T5 dash. So T5 dash is 756.05 kelvin.

Now we have but do not know the pressure at this PX this PX is known to us but we know the HP turbine isentropic efficiency HP turbine is 0.84 that is T4 - T5 dash divide by T4 - T5. Now here we have the value of T4 we have the value of T5 dash we can find the value of T5 now the T5 is 722.35 kelvin. Once we have value of T5 we have value of T4 than T4 by T5 = P2 by PX raise to power gamma - 1 over gamma right.

Now gamma - 1 over gamma is known to us P2 we know it is P2 by P1 is 404 so at P1 is 100 kilopascal it is given here P1 is 100 kilopascal so P2 is 400 kilopascal right. Now from here T4 and T5 are also known to us we can find the PX and the PX is 163.9 kilopascal. Now here we have the value of pressure and temperature here and this is 7 dash right.

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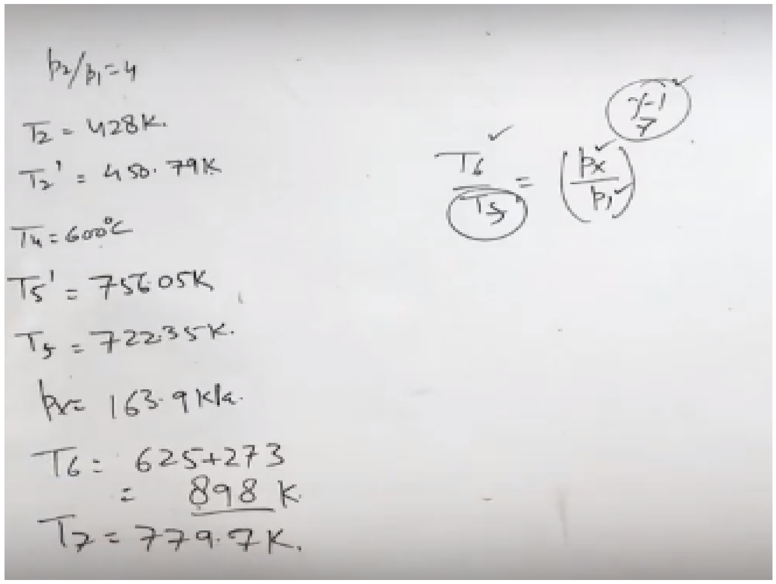

Now we can find the value of T7 because T6 by T7 again = PX by P1 raise to power gamma 1 over gamma. Now we have value of T6 is 625 + 273 = 898 kelvin right. So P6 is with us T7 we have to find out PX is with us P1 with us this is also with us we know all this values.

So T7 is 779.7 kelvin right since we have value of T7 we can easily calculate the value of T7 dash.

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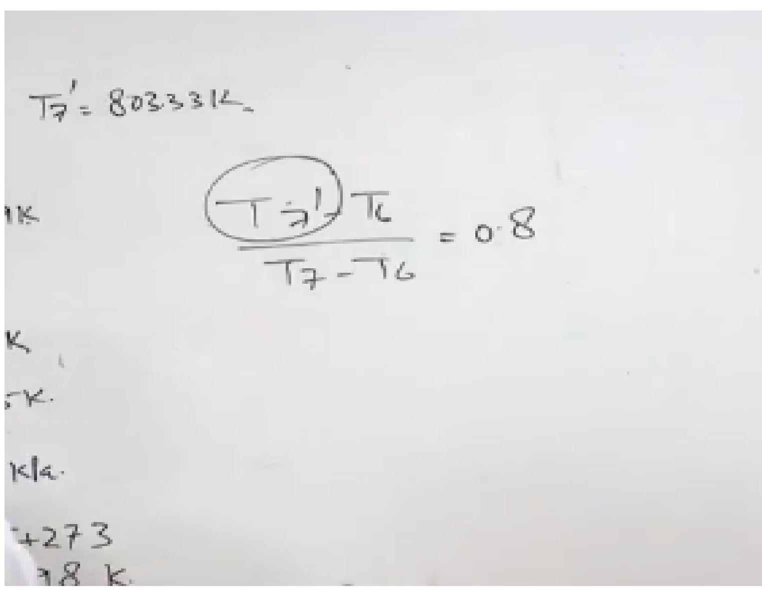

T7 dash - T6 divided by T7 - T6 = isentropic efficiency of low pressure turbine that is .8. Now from here we will get the value of T7 other values are known. So T7 dash is coming 803.33

kelvin. Now we have temperature at all salient points and now we can calculate the energy interaction.

One thing is remaining that temperature is three dash because this temperature will required to find how much heat is added in this process.

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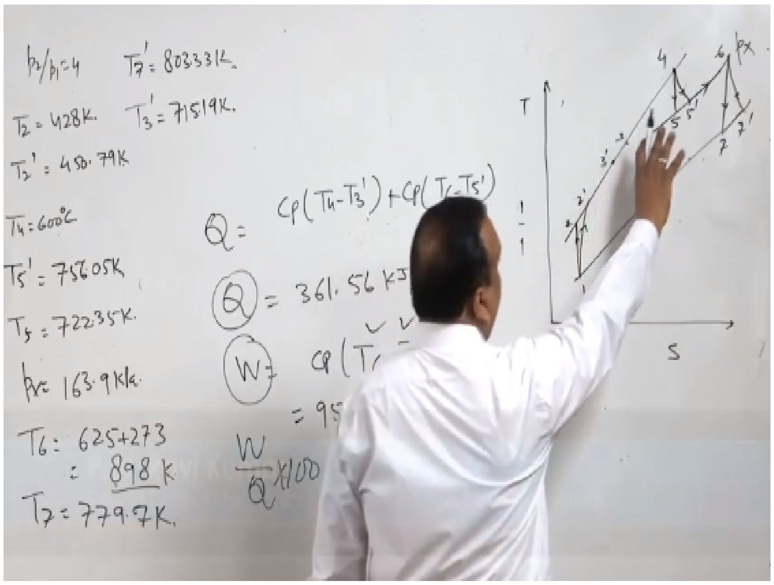

So effectiveness of regeneration is given that is 0.75 and that = T3 dash - T2 dash divided by T7 dash - T2 dash T7 dash this is temperature of exhaust gases and this is the exhaust of the compressor. This is the maximum possible temperature difference or maximum possible heat transfer and this is actual right. So here these values are known this is known this is known T3 dash we can get from here and T3 dash is 715.19 kelvin.

Now we have temperatures at all salient points right now heat transfer Q per KG of air = CP T4 - T3 dash + CP T6 - T5 dash. This is the amount of heat transfer we have the value of all these values with us this will give us the heat transfer of 361.56 kilo joules per KG right. Will be putting T4 T3 dash T6 T5 dash from here and we will be getting this is the amount of heat liberated by burning the fuel in cumulatively in these 2 processes main heating into combustion chart and then reheating in another combustion chamber.

And work output is CP T6 - T7 dash right and we have the value of T6 and T7 also and this will give the work output as 95.14 kilo joules per KG right. And then we will take the ratio W by Q and W by Q multiplied by 100 will give us the thermal efficiency and which is 26.31% right. So this numerical involve the reheating in the cycle and as well as regeneration of the cycle that is all for today from the next class we will start with centrifugal compressors.