MARINE ENGINEERING

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Lecture50

Gas turbine, formula, calculations

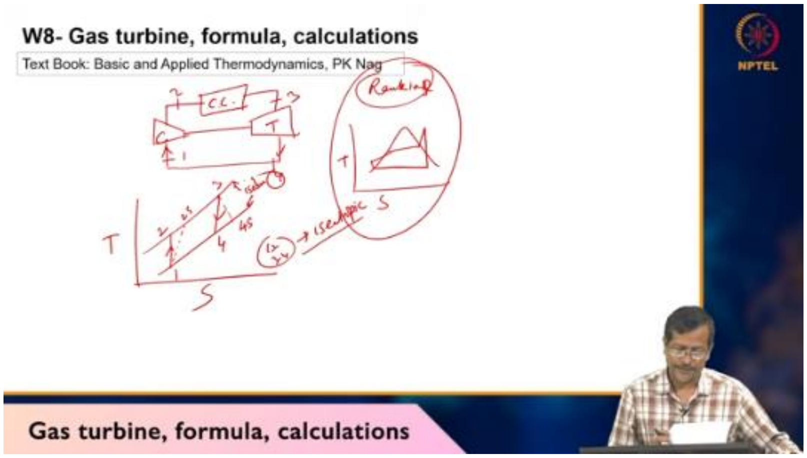
Good morning. Today's topic is on gas turbine formula calculation. So, those things we are moving. So, you have in the previous lecture you have seen the basic fundamental understanding of gas turbine. it is having one compressor system, it is having one shaft, you have one compression chamber, you have one turbine.

compressor compressing air sending to combustion chamber or combustor then you are harnessing energy in turbine now how to calculate the power how much power you are getting in different space so you have to go for ts diagram and pv diagram and we have to see how to calculate how to calculate efficiency and performance so similar way we have calculated for ic engine ic engine is reciprocating ic engine this is also ic engine but this is continuous flow ice engine But dissipating IC engine means like photo cycle, diesel cycle you have calculated. similarly we will see how to calculate for gas turbine system also. gas turbine system already you have seen while compressor is there, one turbine is there, fluid entry, combustion happening, exit is happening.

normally it will be open cycle, but sometime it drops as a closed cycle also. So, 1, 2, 3, 4. 4 ok so compost compressor turbine combustion chamber or combustor ok now T S diagram so T S diagram it will looking like this so in Rankine cycle actually you can remember Rankine cycle T S diagram we drawn we have drawn like this ok this is Rankine cycle, but here my figure will not have any that vapor envelope because we are not condensing anything. we will have compressor 2 to 3, peak temperature or highest temperature will be at 3 actually after combustion.

In IC engine also you have seen that after combustion we are getting highest temperature. 3 to 4 is your turbine. So, 1 to 2 we are assuming isentropic. If it is not isentropic, then 2S you can put, 4S you can put. this is your simple gas turbine system.

it is having then one isobaric process, a constant pressure process, two constant pressure process, that means 2 to 3 and 1 to 4, both are constant pressure process and And two isentropic process, 1 to 2 and 3 to 4 isentropic. Ideal cycle will have two isentropic, two isobaric process. Next one. next one let us see the difference between the cycle, among the cycles, Carnot cycle, Otto cycle, Rankine cycle, Diesel cycle, Erection cycle.



So, many cycles we discuss actually. So, Carnot cycle if I draw in PV diagram, PV, so it will be like this, 1, 2, 3, 4. So, Q coming, Q going. So, this is your Carnot cycle process. Now, if I go for Otto cycle, Otto cycle PV diagram, PV.

we have drawn like this. You can remember IC engine discussion, reciprocating IC engine 1, 2, 3, 4. This is Otto. Then Another cycle I did not discuss actually this is erection cycle PV.

So, they are numbering little bit different but does not matter 3, 4. This is erection. The next is diesel cycle you can remember. Diesel cycle. then your Brayton cycle so this whatever gastronomy system we are discussing this is based on Brayton cycle so PV diagram will be like 2 to 3 so 1 2 3 4

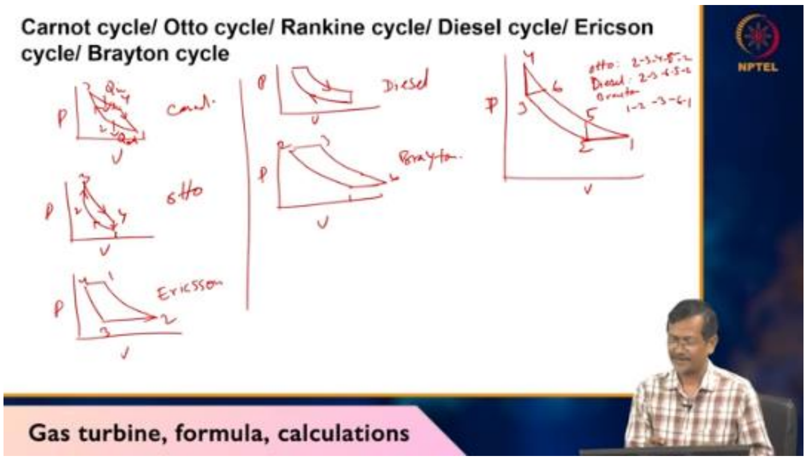
You can see the differences. So, if I draw these basic cycles, let us say erection you ignore and other cycles, common cycle. 1, 2, 3, 4. So, all the cycle actually I want to draw in one cycle T, S. So, 2 to 3 is let us say First, you draw Brayton cycle. So, 1 to 2 constant pressure forces. Wait, wait, wait, wait, wait, wait.

PV or TS. I will draw PV. PV. So, PV diagram let us see. So, 1, 2, 3 is a constant pressure process.

So, heat air intake happening then 2, 2, 3 are compressing. So, 3 to 4 your combustion happening in auto cycle you can see remember you can see the auto cycle 2, 2, 3 is vertical here 3 to 4 and 4, 2, 1. So, 1 to 2 constant pressure process, 2 to 3 adiabatic process, 3 to 4 constant volume process, 4 to 1 again adiabatic process. Now, if I want to draw auto cycle from this one, auto cycle means I will have 2 to 3 process, 3 to 4 process, 4 to, I will have, so auto cycle here, 2, 3, 4, 5. correct everyone okay okay so two three four five is auto cycle now if i want to make this one as a diesel cycle so what will i make two three four five six maybe two three six five two i should make like this

So, this is the cycle. So, if I want to make this one as your Brayton cycle. So, Brayton cycle 1, 2, 3, 1 to 2 intake, 2 to 3 compression, compression by constant heat addition, constant pressure. So, 3 to 6, 6 to 1 again expansion process. this is Brayton cycle.

in single cycle actually I can draw like this. In exam also I can give one single cycle I can ask you to identify which one what cycle. Now, we will discuss details about the Brayton cycle. So, again you should not forget this figure compressor, combustion chamber, turbine expansion, 2 3 4 and instead of making open cycle you can make close also for temporary purpose.



So, W turbine compressor W turbine heat coming Q 1 and heat rejection is happening you can assume here ok. So, net work output W turbine minus W compressor. Now, you draw PV diagram, PV constant pressure process, 2 constant pressure process, 4, 1, 2, 3. Now, TS diagram, TS, so 2 constant pressure line, 1, 4 to 1, 1 to 2 compression process, 2, 3, 4, 4 to 1. So, this is your TS and PV diagram.

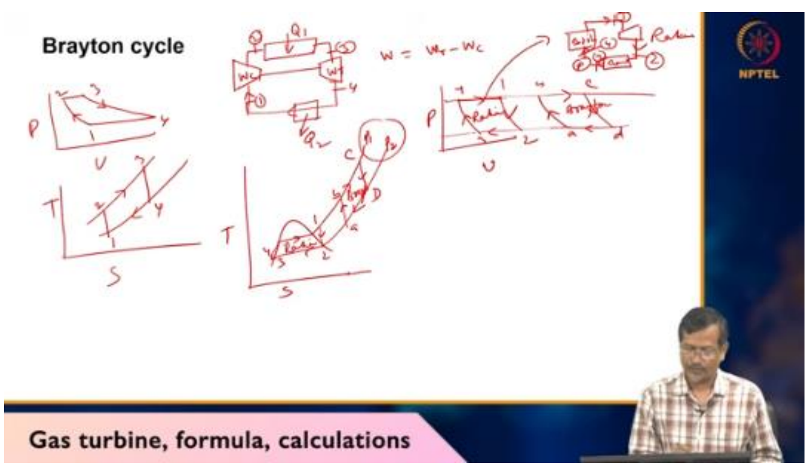
Now, if I want to compare with Rankine cycle. So, how it will look like? TS diagram. 3, 1, 2, 3, 4 then A, B, C, D. This is Rankine, this is Brayton. Brayton is upper side at high temperature because their condensation is not happening.

So, that is why Brayton is on the upper side and pressure range you can see P1, P2 within these two pressure range both are working fine. So, similar way PV diagram if I draw. So, 3 to 4 is compression happening volume reducing 4 to 1 constant pressure process 1 to 2 again expansion happening. So, 3, 4, 1 and A to B compression happening A to B and D, C. This is your Rankine cycle, this is Brayton cycle.

You can see the difference between Rankine cycle and Brayton cycle from these figures. So, Brayton cycle will be working at higher temperature. there will be no condensation. So, there will be no two-phase thing. But Rankine cycle will have two-phase thing.

That is why this vapor envelope will be coming and mixture story will be coming in between. Rankine cycle diagram will be like this. The boiler is there. then turbine, then condenser, then pump. So, if I put the numbers 3 to 4, 3 to 4 is pump, 3, 4 pump, 2 to 3 condenser, after boiler it is 1.

This is Rankine. this is Brayton. So, 1 to 2 expansion process. Whenever you are drawing figure you should give proper arrow symbol otherwise I may cut marks because if you do not understand flow direction then actually there is meaningless of drawing Rankine cycle or Brayton cycle or any type of cycles. Now, we have to calculate the thermal efficiency of Brayton cycle.



So, first you draw T-S diagram, two pressure line, constant pressure line first you have to draw, then 1, 2, 2, 2, 3, 1, 2, 3, 4. So, as according whatever you follow your number notation based on that you have to derive your formula. So, eta thermal efficiency equals

W net, net power output and heat input. So, heat input Q1 and power output wt this is w compressor so w net e net means wc minus wt minus wc divided by q1 q1 is a heat input okay so now if i write like this cp t3 minus t t3 minus t4 minus

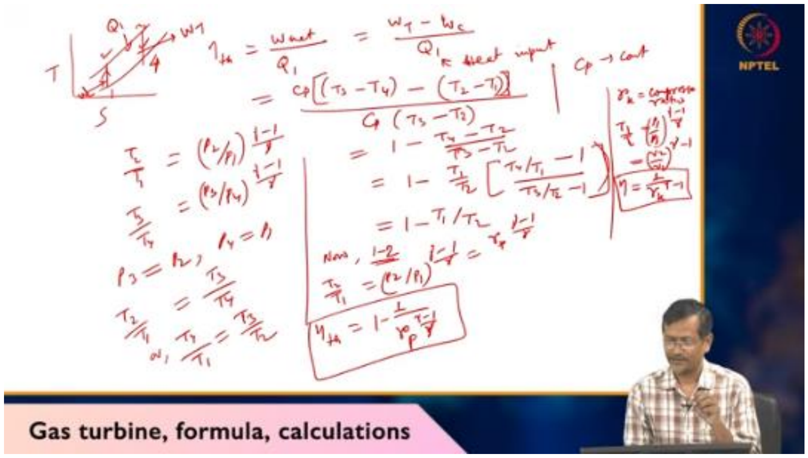
T2 minus T1 divided by Q1. Q1 is Cp again T3 minus T2. We are assuming Cp constant, constant specific heats. So, Cp Cp constant we are assuming. So, T2 by T1 equals P2 by P1

k minus 1 or gamma minus 1 by gamma t3 by t4 equals p3 by p4 gamma minus 1 by gamma p3 equals p2 you can see the same constant pressure line and p4 equals p1 so t2 by t1 equals t3 by t4 or T4 by T1 equals T3 by T2. So, then I can put all the values here 1 minus T4 minus T2 T3 minus T2 equals 1 minus T1 by T2 T4 by T1 minus 1 T3 by T2 minus 1. So, this is giving me 1 minus T1 by T2.

Now, 1 to 2, process 1 to 2, what is happening? T2 by T1 equals T2 by P1 gamma minus 1 by gamma equals Rp pressure ratio gamma minus 1 by gamma Eta thermal efficiency equals 1 minus 1 by r p gamma minus 1 by gamma. So, this formula you should remember for Brayton cycle thermal efficiency or pressure ratio for gamma minus 1 by gamma. Now, if I have compression ratio known, let us say r k is compression ratio.

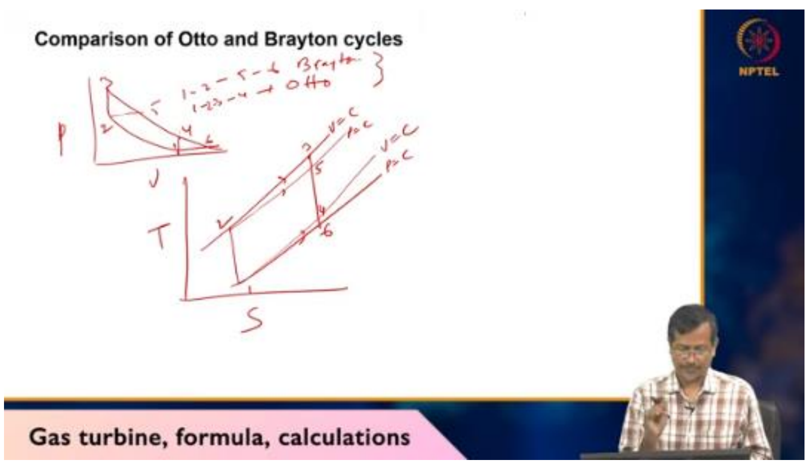
So, in that case T1 by T2 equals P1 by P2 gamma minus 1 by gamma equals V2 by V1 specific volume k minus 1 or gamma minus 1. So, eta equals 1 by Rk gamma minus 1. Rk means compression ratio. So, you have to see whether pressure ratio given or compression ratio given. So, both may not be same.

If compression is given, formula is different, pressure is given, formula is different. So, compression between Otto and Britten cycle, again you have to draw PV diagram. Already we have given in general diagram, so based on that only. 1, 2, 5, 3, 4, 6. 1, 2, 1, 2, 5, 6, Brayton, 1, 2, 5, 6, 6, 1, Brayton, 1, 3, 2, 3, 4, Otto, Otto cycle. So, I will draw this one in TS diagram.



So, two pressure line. And it is like this 1 to 2 constant pressure and 2 to 5, 2 to 5 is constant pressure process. So, this is P equals C, V equals C then. So, 2 to 3 is your 2 to 3 is your volume constant and 2 to 5 is your pressure constant and 1 to 4, 1 to 4 is volume constant and 1 to 6 you can see your pressure constant.

So, this way you can draw your figures. So, you can just compare the figure you can draw in TS diagram. So, Brayton cycle for a safe operating engine is not suitable because this engine cannot handle such large volume flow. But a water cycle or diesel cycle will be handling very smaller amount of volume flow. Next slide.



So effect regeneration and Brayton cycle. So effect of regeneration. So first you have to understand what is regeneration. Regeneration means you are using certain amount of heat to increase your performance. System performance will be increasing.

So let us assume like this. then heat gene addition is here it is here it is going here okay so compressor turbine shaft okay so com from compressor your compressed air is going through this heat exchanger okay this one heat exchanger then your combustor from combustor your fluid is going to turbine and turbine after that you have you have seen already in gas turbine engine of general electric that about 500 degree temperature is there so very high amount of heat is there already so that heat you are using in heat exchanger what you are doing after compression actually increasing air temperature ok so some energy you are extracting from your exhaust heat and increasing that compressed air temperature so that will be reduce your combustor heat input okay so this was regeneration okay so instead of wasting certain amount of heat you are regenerating or you are reusing to increase your compressed air temperature okay so you are using for compressed air temperature okay ah so then what will be my ts diagram then Again, you draw your pressure line 1 to 2 numbering you have to give a number where here it is 1.

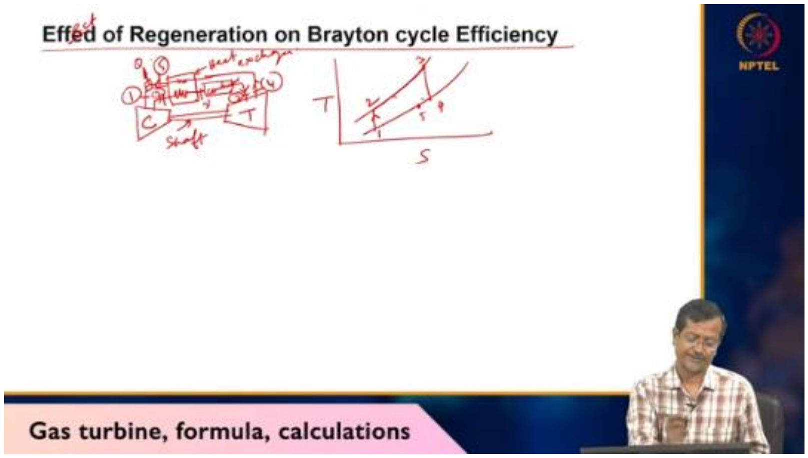
So, they have drawn like complete closed cycle. So, you can create open cycle also does not matter. 1 to 2 your compressor isentropic compression we are happening we are assuming that 2 to 2 to 3, 4, 3. 3 is here. 3 to 4 is here.

4 to 5 they are giving here. Okay, fine. And then 6. Okay, so we will see. 1 to 2 is happening like compression happening.

Then 2 to 3 is your heat addition process. 3 to 4 your turbine work. So, 4 to 1, heat should be rejected at constant pressure. So, what they are doing? 4 to 5, the process is there.

So, 4 to 5 means you are giving heat to at constant temperature. Just wait, wait, wait, wait, wait. two to six okay so four two five just wait wait what is happening here two to six two to six something wrong happened what happened here heat exchanger five is wrong place right location is wrong this is five you're saying maybe three dash you can make so four to five no now four and five pressure is same four to five pressure is same why pressure will be changing right four is four to five pressure is not changing

Then 5. Okay, 5. Then another heat release is happening, they are saying. 5 to 1, how does that work? But pressure you are not changing, no?



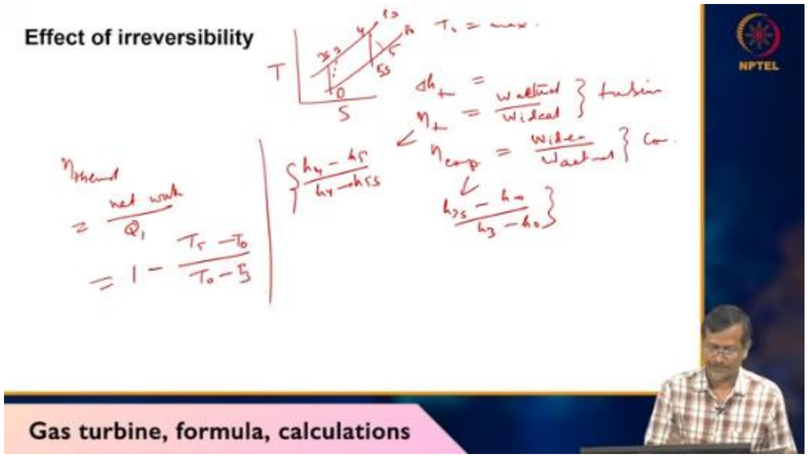
heat exchanger is 2 to 3 now something wrong maybe I will check ok so I will hold it so next day maybe I will check out this part this slide or if I get back later so this one I have to recheck So, we will see effect of irreversibility. Every time I was saying like ideal cycle and actual cycle. So, there will be irreversibility term. So, T s again you draw your cycle 1, 2.

Here they have given 0, 3. So, as it is from some book I am copying 5, 4, 5. So, 0 to 3 s. 4 to 4, this is 5s, 3, this is 5s means they are saying constant entropy, this is 5. This is pO, this is p3 and T4 equals maximum temperature.

So, del H for turbine, work of turbine and eta turbine. So, W actual by W ideal ok. So, eta compressor equals W ideal is for turbine ok W actual. So, you can see the formula is opposite just way because Compressor will be taking more energy.

Turbine will be giving less energy. That is why this is opposite. So, turbine formula becomes H4 minus H5 divided by H4 minus H5S. H4, H5, H4, H5S. Now, for compressor, this formula will be like this.

H3S minus HO H3 minus HO. Now, eta thermal network by Q1 plus 1 minus T5 minus TO, TO minus T3. This is your network thermal efficiency.


Effect of irreversibility
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Gas turbine, formula, calculations