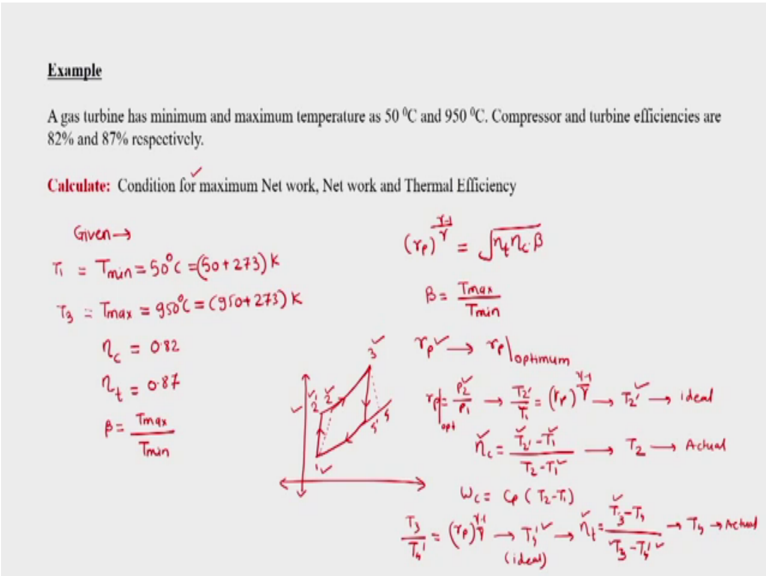
IC Engines and Gas Turbines
Dr. Vinayak N. Kulkarni
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture – 39
Solved Examples for Real Brayton Cycle

(Refer Slide Time: 00:27)



Welcome to the class. In today's class we will see some more examples, but the examples what we have seen in last class where related with the ideal Brayton cycle, where we had most of the times considered that the compressor and turbine have highest which is 100 percent efficiency and then we solved examples accordingly.

Now, we are going to see the new example, that in the first example, it is said that there is a gas turbine which has minimum and maximum temperature as 50 degree Celsius and 950 degree Celsius. Compressor and turbine efficiencies are 82 percent and 87 percent respectively and we are suppose to find out maximum network, condition, then network and thermal efficiency.

So, the things which are given to us are T min, which we are actually having, given conditions and in that we are having T min which is 50 degree Celsius, so we have it as 50 plus 273 as Kelvin. Then T max we are told as 950 degree Celsius, so it is 950 plus 273 Kelvin, so we are given with this. Then along with that we are given with isentropic efficiency of compressor is 0.82 and isentropic efficiency of turbine is 0.87.

So, this example is based on the derivation which we did for the network to be maximum condition. So, in that we had derived that r p raised to gamma minus 1 upon gamma is equal to eta t eta c into beta. Here beta is equal to T max upon T min. So, we know that beta is the ratio of maximum and minimum temperature, but in this example maximum and minimum temperatures are given to us. So, practically in this example beta is also given to us; T max upon T min. So, this is known to us. So, beta is known, eta t is known, eta c is known, so we can find out r p. Basically this r p is r p optimum, so we know that what is the condition for maximum net work output. So, this r p gives us the condition for maximum net work output. So, condition is known to us.

Now, what we can do is we can draw the T s diagram. In this T s diagram this is isentropic 1 2 3, this is ideal cycle and then this is 2 dash and 2 and this is 4 dash and 4. So, now, we know everything at T 1, we know only pressure at T 2, we know temperature as T 3 and we do know temperature at 4. So, we can use the formulas what we used and what we derived for getting the properties at all the corners.

So, in this case we know now pressure ratio. So, pressure ratio means, we know P 2 by P 1 and that is our r p, and in this case it is optimum. So, r p optimum is known to us. So, we can take initial condition as 1 bar, we will assume that then we know P 2, in that case once we know P 1, we know P 2, since we know r p knowing this we can find out T 2 by T 1 and that is equal to r p bracket raised to gamma minus 1 upon gamma. So, we know r p which is r p optimum, we know T 1 which is minimum temperature. Basically from the cycle this is T 1 and from the cycle this is T 3.

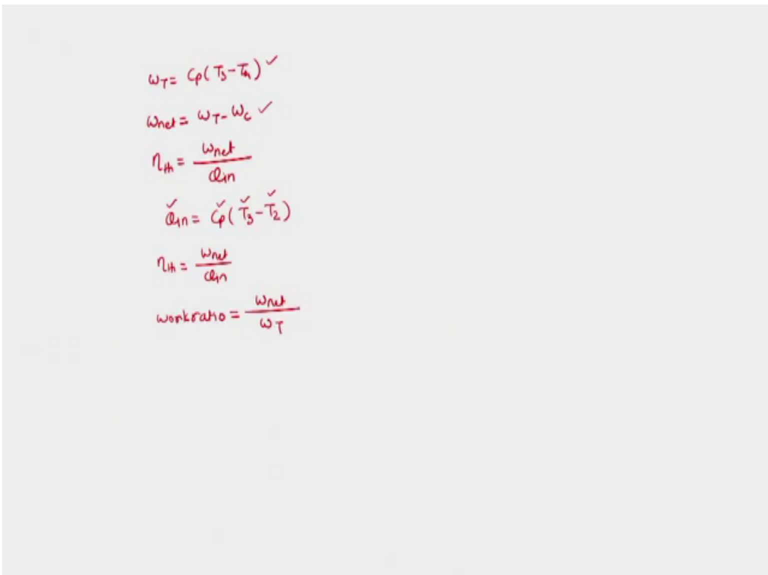
So, we know now T 2. From this formula we know T 2, so now, we know T 2 we know P 2. Once T 2 and P 2 are known anyway we know T 3, so then we can find out. But then there is a problem, this is T 2 dash is what we know, but we do not know T 2. So, for using we have to use formula for the compressor efficiency. We know compressor efficiency formula is ideal work T 2 dash minus T 1 divided by T 2 minus T 1

So, in this formula from the isentropic relation; T 2 dash is known to us, T 1 is known to us already, T 1 is also known to us here, compressor efficiency is given. Then this using the isentropic efficiency formula we can find out T 2. So, one point to be remembered here that isentropic formula are only usable for the ideal temperature at the exit of the condition, but then we will use compressor efficiency to formula to get actual temperature at the exit of the compressor. So, then we know T 2.

Previously from isentropic we know T 2 dash, we know T 3. So, then basically we can know what is the work of the compressor w c is C p into T 2 minus T 1. We know air specific heat of air is 1.005 kilo joule per k Kelvin. So, knowing this we know the net compressor work. Having the compressor work known then we can find out turbine work, but for turbine work we should know T 4. So, to know T 4 basically first what we have to do, is we know r p.

Once we know r p we know T 3 by T 4 dash is equal to r p raised to gamma minus 1 upon gamma. So, since T 3 is known then we can find out from this formula T 4 dash. Once T 4 dash is known then we can use the formula for turbine efficiency. And turbine efficiency is actual work T 3 minus T 4 divided by ideal work which is T 3 minus T 4 dash. So, in this formula T 4 dash is known, T 3 is known, turbine efficiency is given, then we can find out T 4. Thus T 4 which is actual temperature is found out from the turbine efficiency formula and in case of isentropic we found out ideal temperature at the exit of the turbine. So, thus we can now find out the turbine work. So, w T is equal to C p into T 3 minus T 4.

(Refer Slide Time: 08:28)



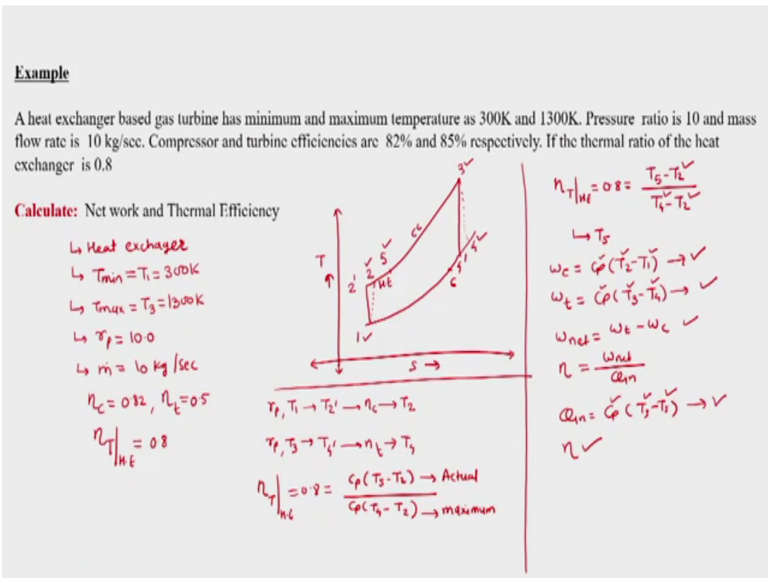
So, here again we are using or assuming that air is the gas which is present in the turbine, so 1.005 into T 3 minus T 4; so, we got turbine work, then we know w net which is turbine work minus compressor work. So, this is how we can find out turbine work minus compressor work which is network, then it is told us to find out the thermal efficiency.

So, thermal efficiency of the plant is also simple to evaluate, since we know thermal efficiency is w net upon Q in, but the problem is we do not know Q in. So, Q in is equal to C p into T 3 minus T 2. So, it is not T 2 dash, you can see this is the process of heat addition. Heat is getting added from 2 to 3. So, heat is getting added from 2 to 3. So, T 3 is known, T 2 is known, C p is known, so we know Q in. So, knowing the Q in we can find out thermal efficiency.

So, this is how we would have solved the problem. And this problem is a special problem, since this problem deals with optimum network condition, and this formula we have derived. There would be one more thing which some people would ask in the example and then that is work ratio.

So, work ratio, we have seen that work ratio is w net upon w T which is turbine work. So, turbine work is found out, w net is found out, so we can find out work ratio. And we had seen long back in one of the classes what is the usefulness of work ratio. We know that work ratio has to be closer to 1. Higher the work ratio it is good, the plant is insensitive to or less sensitive to the component efficiencies we have seen that. So, this is done for this example.

(Refer Slide Time: 10:52)



So, for next example we will see that, in this example it is told that there is a heat exchanger based gas turbine power plant, and it has minimum and maximum temperature as 300 Kelvin and 1300 Kelvin. So, what is given to us in this example is, we are told that there is heat exchanger, it is told to us. And then it is told to us that T min, so for us it is equal to T 1 is equal to 300 Kelvin. We know that T max is equal to T 3 is equal to 1300 Kelvin, then pressure ratio is ten. Then it is also told that r p is equal to 10, mass flow rate is also 10 kg per second. We are told that mass flow rate which is m dot is 10 k g per second.

Now, we are given that thermal efficiency of compressor is 0.82 and thermal isentropic efficiency of compressor is 0.82 and isentropic efficiency of turbine is 0.85, but there is one more thing extra given that thermal ratio is 0.8 thermal ratio. I will denote it as capital T for heat exchanger and that is told as 0.8.

So, this is new example for us, where now we are having three components which is a compressor, which is a turbine and which is a heat exchanger and both are, or other all are non ideal. So, let us draw first T s diagram. So, in this T s diagram what we have is, first one, 1 to 2 dash, 2 dash to 2, 2 to 3, 3 to 4 and 3 to 3 to 4 is real process, 3 to 4 dash is ideal process. Then we have 5 here and then we have 6 here. So, these points correspond to the heat exchanger process. We know that 2 to 5 is the heat addition in the heat exchanger before going to the combustion chamber. So, this is heat exchanger, this is combustion chamber. So, 5 to 3 is only heat added in the combustion chamber

Now, we are supposed to derive or find out the network and thermal efficiency. So, for that all sake, let us try solving this example. What is known to us is T 1, what is given to is r p. Again knowing the r p, knowing the T 1, we know that we can find out T 2 dash, this is what we have seen from the isentropic relation r p raised to gamma minus 1 upon gamma is equal to T 2 dash upon T 1. So, T 1 is known r p is known gamma; we are going to take it for air which is 1.4 for the sake of simplicity since it is again not told to us.

So, simplest assumption is for air, so we know T 2 dash. But now using the T 2 dash and T 1 we can use further compressor efficiency formula and find out T 2. We know that compressor efficiency is ideal network input net, ideal work requirement divided by actual work requirement. So, ideal work requirement is T 2 dash minus T 1 and actual work requirement is proportional with T 2 minus T 1, so this will give us T 2.

Then we can parallelly do it for the turbine. So, we know r p for the turbine, we know T 3 which is maximum temperature of the cycle and then from that using the isentropic relation we can find out T 4 dash. So, T 4 dash is known to us now from isentropic relation. Then we can use turbine work formula to find out T 4. Again turbine work, turbine efficiency which is isentropic efficiency is equal to actual turbine work divided by maximum turbine work. Actual turbine work is T 3 minus T 4, maximum turbine work is T 3 minus T 4 dash. Only T 4 is unknown so we can find out.

Now, in this example there is a new thing which is told to us which is turbine thermal ratio of the heat exchanger; of the heat exchanger is 0.8. So, this is what it is told to us thermal ratio of the heat exchanger. So, we know that when we derive the formula we had taken it as 1, and based upon that we derived some formulas. What is this? This is actually transfer divided by maximum possible transfer. What is actually transfer? Actually transfer is, basically it is a constant pressure heat addition in the heat exchanger, so C p into T 5 minus T 2 divided by. What is maximum possible heat transfer? It is C p into T 4 minus T 2, C p into T 4 minus T 2. So, this is actual heat transfer. This is maximum heat transfer.

We have seen if we would have ideal turbine and compressor then we should have 5, T 5 is equal to T 4 and then we should have T 6 is equal to T 2. This is what in ideal case we had seen. So, thermal coefficient of heat exchanger being 0.8, so we have T 5 minus T 2 divided by T 4 minus T 2. So, in this formula 4 is known to us, 2 is known to us, so this formula would give us T 5.

So, we know now everything at 1, everything at 2, everything at 5, everything at 3 and everything at 4. So, we now know all the properties at all the corners which are for the cycle. So, this example is basically telling us why it is important to write or draw the power plant cycle thermodynamic cycle before solving the example. So, by first drawing the cycle and then proceeding with the example would help us in knowing what properties are known to us at all the corners, so this should be explicit. Then we can start finding out work. We know that compressor work is C p into T 5 T 2 minus T 1, this is known to us or some people can use the formula which is C p into T 2 dash minus T 1, but in that case they have to divide this by compressor efficiency. Then we know T 2, we know T 1 we know C p, we found out C p we found out w c which is compressor work, then we can find out turbine work which is C p into T 3 minus T 4. Here as well T 3 is known, T 4 is known, C p is known we found out turbine work.

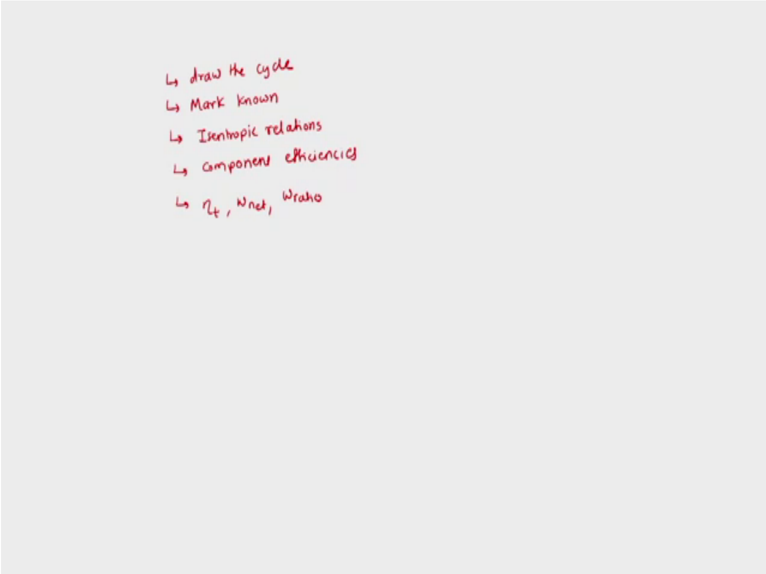
So, we know that w net is equal to turbine work minus compressor work. So, we eventually found out network then now we have to find out the efficiency of the power plant. So, for that we know efficiency of the power plant is w net divided by Q in. So, since we do not know Q in we can find out Q in as C p into T 3 minus T 5. So, we should know T 5. So, T 5 is known to us from the heat exchanger formula, so we know T 5, we know T 3, we know C p, so we know Q in. So, putting the Q in we know efficiency of the thermal power plant.

Basically without or with heat exchanger we know that network would not have what altered, what has got altered is Q in. So, since Q in has decreased efficiency would increase. So, this is how we have to solve the examples which are there with the components being non ideal. So, every component would have certain efficiency associated with. So, in case of the heat exchanger it will be called as thermal ratio or some people would call it as effectiveness of the heat exchanger, then these numbers will be associated with actual divided by maximum possible heat transfer data.

So, then in case of the thermal power plant or gas turbine based power plant with exchanger plus intercooler plus reheater. We; obviously, would have efficiencies of multiple compressors which might be different, multiple turbines which might be again different.

So, such example would lead to additional complexities since we have two turbines with two efficiencies, and we have two compressors with two efficiencies, but problems are simple from the perspective that we now have established the procedure how to solve the example.

(Refer Slide Time: 21:30)



So, we have to first what we have to do, is how to solve the example. In this case first draw the cycle and then mark what are the known things. Then in this case we have to first use isentropic relations to find out the properties of the ideal cycle corners. So, ideal cycle has corners 2 dash, 4 dash 3 4. So, those corner properties we can find out from isentropic relation. And then we have to use component efficiencies to find out the temperatures at the actual corners. Actual corners are 2 4 5 6, so these are actual corners. So, we have to first find out isentropic relation then go for actual efficiencies which are component efficiencies and then find out corner properties, and then find out performance parameters. So, this performance parameters are for the cycle.

So, first performance parameter will be thermal efficiency of the cycle, and then there will be w net of the cycle, then there will be work ratio of the cycle. So, these properties we can find out. So, having said this, this ends today's class where we have understood how to solve the examples for the gas turbine based power plant if there are non ideal components.

Thank you.