Course Name: Engine System and Performance
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Lec 35: CI engine performance, factors affecting engine performance

I welcome you all to the session on engine system and performance. Today, we shall discuss CI engine performance and identify a few factors that affect CI engine performance. In our last two classes, we discussed SI engine performance, representing performance curves and then performance maps. If we talk about CI engine performance, essentially the parameters used to specify or indicate engine performance are the same, like indicated horsepower, brake horsepower, mechanical efficiency, and indicated thermal efficiency. As we discussed earlier, if we need to compare the performance of two dissimilar engines, there are some specific parameters used to represent performance based on the dataset. These are BSFC (brake-specific fuel consumption) parameters.

Brake mean effective pressure and engine mean speed. Now, if we recall all those performance curves, they will be qualitatively similar even for CI engines. Why am I saying 'qualitatively'? Because if we measure engine performance in terms of efficiency, indicated horsepower, or brake horsepower—those are used to measure indicated thermal efficiency and brake thermal efficiency—quantitatively, efficiency will be higher for CI engines because, as we know, the compression ratio is higher for CI engines. So, we can say that the engine performance curves we discussed in the context of SI engines will be similar to measure or indicate the performance of CI engines as well. But qualitatively and quantitatively, these curves will be slightly different from what we saw earlier in the context of SI engines. Now, you all have studied in your undergraduate internal combustion engine course that to establish efficiencies like indicated thermal efficiency, mechanical efficiency, and most importantly, volumetric efficiency. All these efficiencies are established in mathematical form, to be precise, by comparing the processes that occur in real engines with air-standard cycles. And you have studied that there are some variations between air-standard cycles and the cycles used for SI and CI engines.

And certainly, some differences you have seen, studied by this time, those are essentially considerations of constant specific heat during the cycle. Then, assuming the cycle to be a thermodynamic cycle and, most importantly, assuming air to be an ideal gas. But there are some common, factors that for both the CI and SI engines, if we would like to compare the actual or real cycle and the air standard cycle.

But in addition to these common factors, there are some unique features which are special to the operation of CI engines. So, we shall discuss those special features, and those features or factors really are very important for the performance of CI engines. But before we discuss those unique features, let us briefly recapitulate our understanding of this particular aspect: the basic difference between the air standard cycle and real cycles. So, for both SI and CI engines, these factors are common, so essentially, we are trying to recapitulate the difference between the air cycle and the real engine cycle. Let us quickly discuss all these. So, the first one is certainly, the cycle or cycles used to compare the processes of a CI engine or of an SI engine; these cycles are not thermodynamic cycles.

Rather, these cycles are called as mechanical cycles because a cycle is said to be a thermodynamic cycle if the composition and mass of the working substance will not be changed at the end of the cycle, what we can understand from the cycle or real cycle of any engine, we see that essentially air is drawn into the engine cylinder during intake stroke or sometimes it is 90% air or 10% depending upon the requirement that is charged air fuel mixture is introduced into the engine cylinder during intake stroke while at the end of the cycle that is during or at the end of exhaust stroke we get some combustion products. So, compositions are not same and mass is also not same for the working substance. So, this is essentially mechanical cycle not the thermodynamic cycle.

Then number 2 is ideal gas assumption. So, we assume that air which is drawn into the engine cylinder for the CI engines, even for the modern CI engines, it is not only pure air that is drawn into the engine cylinder during intake stroke, rather it is air-fuel mixture because there are multiport fuel injection systems. It is called MPFI.

For a multiport fuel injection system, air fuel is sprayed into the air or incoming air even in the intake manifold or different locations. So, we can say that 90% or 92% or 91% is fresh air and remaining 7% is liquid fuel or if it is fuel in the vapor form, but still it is not pure air. So, we can still consider the intake air or air which is drawn into the engine cylinder during intake stroke to be an ideal gas.

But, approximating combustion products or exhaust gases, as an ideal gas, is not a very important or rather correct assumption. I should say it is a wild assumption rather because approximating combustion products or combustion gases as ideal gases is— or as an ideal gas, or mixture of ideal gases, maybe we will reduce, calculation or our analysis, but it will introduce some errors in the analysis. So, this is what is very important. But, the air-fuel mixture, which is drawn into the engine cylinder during the intake stroke, to be an ideal gas, it is still okay because 91% or 92%, depending upon the requirement, is fresh air while the remaining 7% or 8% is fuel. So, it is still okay, but combustion gases can no longer be treated as, an ideal gas. So, this is important. Number three is, constant specific heats—that is, constant C_p, C_v, etc. So, try to understand: we had assumed that, the combustion process can be mimicked by a constant-volume or constant-pressure heat addition process, then we assume C_v to remain constant throughout the process, while if it is the combustion process mimicked by a constant-pressure heat addition process, then it is assumed that C_p will remain constant throughout the process. But it won't be true in real applications because C_p and C_v are functions of temperature. So, certainly, even if we talk about an ideal gas, C_p and C_v of an ideal gas—these two specific heats are not constant; rather, they are functions of temperature. Certainly, if we consider the gas to be a calorically perfect gas, which is a special type of ideal gas, we can assume C_p and C_v to be constant. But assuming incoming air or intake air to be an ideal gas and considering the charge to be an ideal gas and mimicking the combustion process by a constant-volume or constant-pressure heat addition process wherein maintaining C_p and C_v constant is really an approximation, and it will certainly lead to some error. Then, number four is heat loss.

So, all these are two different conditions ways of heat loss: first of all, during combustion, we have all studied that when combustion occurs, the temperature and pressure of the working substance or charge will increase, and then a certain amount of heat will transfer from the combustion chamber through, the engine cylinder wall to the coolant. So, this heat transfer will, reduce the peak pressure and temperature of the cycle, which in turn will reduce work output. So, heat transfer during combustion, and it will reduce peak pressure and temperature, and the eventual consequence of this event is a reduction in work output, reduction of work output. Similarly, heat loss will occur during expansion or the power stroke. So, During expansion, also, we know the piston will travel from the inner dead center or top dead center to the outer dead center or bottom dead center, and while combustion gases expand during the process of expansion, a certain amount of heat will be transferred from the combustion gases to, the surroundings or even to the coolant because we need to supply coolant continuously essentially to save several parts of the engine from excessive heating or their excessive heating. So, this heat transfer during the expansion stroke will also lower pressure and temperature (P and T). So, heat transfer during the conversion process will lower peak pressure and temperature, which in turn will reduce the work output, but during the expansion process, transfer of heat from the combustion gases to the coolant or surrounding will lower pressure and temperature as well, and this will allow pressure and temperature to become lower. So, if I go to the next slide, heat transfer during the expansion process will lower the pressure (P) and temperature (T) below the ideal isentropic process at the end of the power stroke. At the end of the power stroke. So, that isentropic compression process and expansion process, these two processes are approximated with reversible adiabatic processes. So, those are isentropic processes. So, if we really consider the transfer of heat during the expansion stroke, that is the transfer of heat from the combustion gases to the coolant or surroundings, this process will allow pressure and temperature to go even lower or below the ideal isentropic process at the end of the power stroke. So, this is the case, and if it is the case, the eventual consequence of this particular case will be the reduction in indicated thermal efficiency, so, this is the 4.

And let us consider point 5, that is, combustion requires finite time. So this means any process needs some non-zero finite time, but if we assume that the combustion process is instantaneous, it means it is really not possible to transfer heat instantaneously. That means, if we consider the real process, wherein combustion will require a certain amount of time, as a result, heat transfer will not be instantaneous.

And if it is not the case, then the assumptions of constant volume or constant pressure, these two will not be true. And hence, the actual cycle will certainly deviate from the ideal one. Then number six is, that is, blowdown requires finite time. So, we have studied that when the piston is traveling from top dead center to the bottom dead center, before it reaches BDC, that is, bottom dead center, the exhaust valve is allowed to open. Nowadays, everything is electronically controlled. No valve is controlled by a cam and follower mechanism.

If that is the case, then there certainly, with the aid of an electronic control unit, we can really minimize or reduce the valve timing or the time needed for the valve operation. But what will happen if the valve or exhaust valve is allowed to open before the piston reaches BDC during the end of the expansion stroke? So, what will happen? Certainly, that means the piston did not reach BDC, we are allowing the exhaust valve to open, and a certain amount of combustion gases will escape from the engine cylinder to the surroundings. And then, a certain amount of work output will be lost because if we reduce the gas pressure, the thrust that will be acting or, will be applied on the piston face will be reduced, and as a result, certain work output will be lost.

So, this is the consequence of this particular event: that some work at the later part of expansion is lost. And if we go to the last point, that is point number 7, which is the valve timing actuation. So, this is again a very important common factor, which is common for both SI and CI engines. This particular factor is responsible for making a difference between the ideal or air cycle and the real cycle. So, valve timing, nowadays no valve is operated using a cam and follower mechanism.

Instead, everything is controlled by an electronically controlled unit. Now, if we can reduce the timings for the valve operation, certainly we can control the amount of air to be drawn into the engine cylinder. We can also control the elimination or reduction of manual intervention. Additionally, as I mentioned, proper valve timing is crucial since the opening and closing of valves require some finite time. So, the delay associated with valve opening and closing will also create some issues with the total amount of exhaust gases escaping from the engine cylinder and the total amount of air drawn into the engine cylinder. And hence, the actual scenario will certainly be different from what is considered in the exhaust.

Ideal air cycle. So, considering all this, the consequence is well known. From the indicated diagram, if you recall, there is a particular period known as valve overlap, where both valves are open. During this time, the intake valve remains open while the exhaust valve is also open, allowed to open during the intake stroke. So, a certain amount of fresh air or fresh charge will allow the residue of the combustion gases to leave as the exhaust valve remains open. While doing so, some fresh charge will also be lost with the exhaust gases, essentially reducing the overall efficiency of the engine. So, the consequence, this leads to valve overlap. This part essentially deviates the real cycle from the ideal one, resulting in a deviation of the real cycle from the from the ideal cycle. So, these are actually the common differences for both CI and SI engine operations. Since these factors are common, we can assume that they are responsible for creating differences between the real cycle and the actual or ideal air cycle. So, as I mentioned, there are some special or unique features specific to CI engine operation, and we shall discuss those factors, as they affect CI engine performance. So, if we now write the unique features or factors that are special to the operation of CI units, as such, while I am explaining this, it is very important to know all these unique features or factors, as they also affect engine performance.

As I said that objective of today's class is to discuss about the factors affecting CI engine performance. Let us now try to list down all these factors and we will see in which capacity all these factors try to reduce or affect the engine performance. So, first one is If I write number one is non-constant pressure combustion of fuel. So essentially now we are talking about CI engines.

So, we know that in a CI engine, combustion process is mimicked by a constant pressure heat addition process. But in reality, it is seen that assumption of constant pressure combustion process, that is if we assume that combustion process which is mimicked by a constant pressure heat addition process is not always true for the CI engines. So, this is not always true for the CI engines. So, this is maybe that we had seen that this is maybe for actual CI engine cycle. Constant pressure heat addition is only approximated at lower speed range. But if the engine operates at higher speed range then this is not a case so that means throughout the range of the speed if we assume that the combustion process can be well mimicked by a constant pressure heat addition process then essentially you are trying to invite some error in the analysis, so this is very important point. This is true but at higher speed range. This approximates more or less is combustion process, a constant volume process.

So, this is which is very important to at this point. So, if you go to discuss about the next point, point number 2, that is dissociation, which is, that dissociation means at high temperature, fuel will start dissociating.

So, dissociation the rise in temperature inside the combustion chamber particularly for the CI engine is relatively high as the compression ratio is high. So, since the compression ratio is high, so essentially pressure will be very high at the end of the compression stroke and at the moment or at the end of the compression stroke when fuel will be burnt then again, the rise in pressure and temperature will be very high and at that temperature fuel may be dissociated, so dissociation will be there. Now, this is a common factor though for both SI and CI engines. CI engines or CI engines deal with heterogeneous mixture and the mixture is lean as well. So, for this, these two factors reduce the gas temperature and the possibility of dissociation becomes less. So, this is one important point. So, though this is a common factor for both SI and CI engines.

Typically, it is this particular aspect that is more vulnerable for CI engines because CI engines are typically operated at relatively high temperatures. But the question is, rather, the most important part is that CI engines deal with a heterogeneous mixture of fuel and also with a lean mixture. Hence, the gas temperature will be reduced. Or it will be reduced because of these two factors, which in turn will reduce the possibility of dissociation.

So, the third point is blowdown loss. what blowdown loss is? Because a few minutes back, I said that the exhaust valve is allowed to open before the piston reaches BDC during the end of the expansion stroke. And it essentially, reduces the gas pressure in the combustion chamber. The idea is to remove a certain amount of combustion gases before the piston again travels back from BDC towards TDC.

But in doing so, what is essentially done is the total work output towards the end or later part of the expansion stroke. So, this is very common even for CI engines. So, blowdown losses. This is similar for both SI and CI engines. Certainly, if the engines are four-stroke cycle engines, but this part, is significant for two-stroke cycle CI engines because the reason is, this is mainly due to the shortened, effective power stroke, which is necessary for the early release of burnt gas in order to achieve better scavenging. So, we know scavenging is a process wherein combustion gases are automatically allowed to leave the combustion chamber by the introduction of intake or fresh charge. So, that is why the power stroke is effectively shortened, which is essential for the early release of burnt gas or gases to achieve better scavenging. Then the last point is pumping loss. So, number four is pumping loss. So, let me draw for this particular point. So, if we try to draw the indicator diagram that we have studied in our basic internal combustion engine course.

So, this is, if we try to draw the indicator diagram. So, you can understand. So, this is called positive work, and this is negative work. So, this negative work is essentially blow-down work.

Now, the cycle absorbs energy. It absorbs work during this part of the cycle, and this is called pump work. So, this absorbs work, energy, or certainly energy in the form of work from the engine. We know very well that we get power output from the power stroke only, while to operate or to execute the three other strokes, we need to supply power to the engine. The cycle absorbs work from the engine to have this particular, cycle or process. Now, this is known as pumping loss. So, what will happen, is that pumping loss is very small for, CI engines in a four-stroke cycle.

For four-stroke cycle CI engines, negative work or pumping loss exists but is very small. Since there is no throttle, in the intake manifold. But this is very small, as we have written for the four-stroke cycle SI engine, while this is significant for two-stroke cycle engines. So, we need to have something in real applications so that, though it is very small for the four-stroke cycle SI engine, this should be reduced essentially to improve the engine efficiency.

So, the last part that I would like to discuss is air consumption in a CI engine. So, we all know that for the CI engines, there is no throttle valve, but for the SI engines, we have seen that there is a throttle valve. Essentially, what is done by controlling the throttle position is that if you try to recall the performance maps, then you had seen that the upper part of the map corresponds to full throttle power output or operating characteristics, while the lower part of the map corresponds to part-load operating characteristics. But in the case of a CI engine, there is no throttle valve.

So, essentially what is done, the fuel is controlled to control the work output. So, two three lines. So, no throttle valve to control the air flow. That is important. Power output is controlled by the fuel amount.

So that means for a given engine speed, though this is true, but if engine speed increases, certainly the amount of air to be drawn into the engine cylinder will be more, then frictional loss also will be more. So, let me make you understand that though there is no throttle valve to control the amount of air to be drawn into the engine cylinder, essentially power output is controlled by the mass flow rate of fuel. This is true for a constant speed, but as the engine speed increases, the amount of air to be drawn into the engine cylinder will increase, and also the frictional losses will increase. So, all these things are not taken into account in the ideal cycles, and also, we know that if we have even given inlet and exhaust valve timing, then we really can control the amount of air to be drawn into the engine cylinder.

Now controlling the valve timing rather intake and exhaust valve timing, we really cannot optimize the engine performance at higher and lower speed. So, what is important to be mentioned here is that the volumetric efficiency is again coming or seems to be an important factor for the SI engine performance. So, the amount of air which should be drawn into the engine cylinder, though it is not controlled by the throttle valve, but plays an important role for the CI engine performance. And this is not only the amount of trapped air inside the engine cylinder, but the proper utilization of the trapped air should be ensured to have better engine performance.

So, to summarize today's discussion, we have recapitulated the basic differences between air cycle and real engine cycles for both CI and SI engines. Thereafter, we have identified a few unique features which are solely responsible for the CI engine operation, as those unique features differentiate the actual CI engine cycle from the air standard cycle. Then, listing down all these important unique features, we have explained each and every point. Finally, we saw that air consumption in a CI engine is also very important, which in turn indicates that volumetric efficiency is crucial for CI engine performance.

So, with this, I will stop here today, and we shall continue our discussion in the next class.