Thermal Engineering: Basic and Applied
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Lecture – 52
Performance Analysis parameters of IC Engine

I welcome you all to this session of thermal engineering basic and applied and today we shall discuss about several parameters those are directly related to the performance of the internal combustion engine. If we recall in the last class, we have talked about the mean effective pressure and we have seen that mean effective pressure is an important parameter for the comparison of engine performance.

And we had seen that when work output is expressed then the concept of mean effective pressure is very useful and from there we could write several forms of mean effective pressure considering different works.

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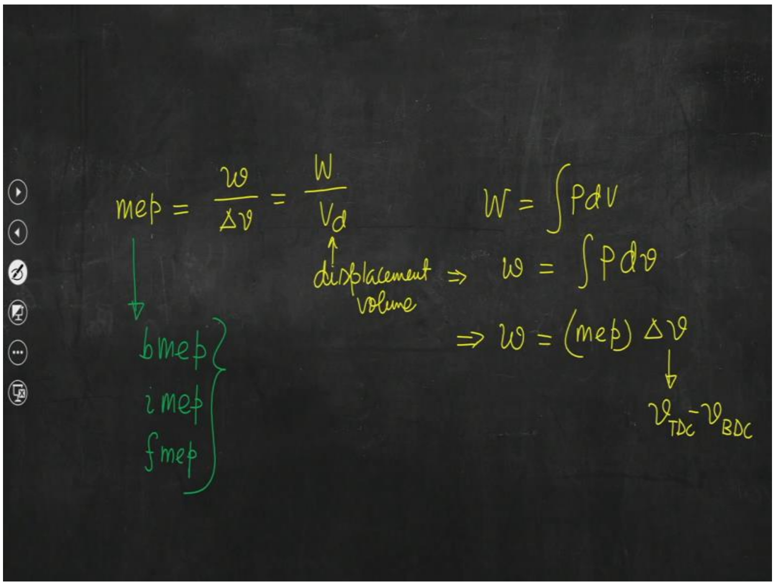

So, if we discuss about the mean effective pressure that we had written in the last class, as such if we write the expression of work done again $w = \int Pdv$ and we had also discussed that very often engines are multi cylinder. So, it is always convenient to write the expression per unit mass of the gas in the combustion chamber. And we had seen that the pressure inside the cylinder is continuously changing so, though it is the differential volume dv that is the displacement by the piston. So, what would be the work done being impressed on the piston be it the work which is available inside the cylinder or be it the work which is available at the crankshaft. So, P is very difficult to calculate because it is changing continuously with time also there is a spatial variation of pressure.

So, what I could write in the last class that $w = (mep)\Delta v$ and this Δv is basically V_{TDC} - V_{BDC}. So, what we can write from this mean effective pressure is equal to W divided by Δv. Now it is not mandatory that we should always write this quantity in terms of specific quantities we also can write like this W/V_d.

So, this V_d is the displacement volume. Now we shall discuss about a few important parameters those are directly related to the performance measurement. So, why mean effective pressure is important, mean effective pressure the concept we are bringing here only to get rid out of that pressure is changing continuously in the combustion chamber.

Now for engine in terms of design as well as the work output if we compare several engines, we must have a common parameter and what the common parameter would be for such a case when we are trying to compare the engine performance or even in the engine design, you can tell me that torque may be an important parameter or the power may be an important parameter.

So, if we consider torque for as a common parameter for comparing engine in terms of the design as well as output may be larger engine always will look better. While if we consider power as the parameter for the comparison of engine performance or engine design then higher speed becomes important. But now if we consider mean effective pressure as a common parameter for comparison of engine design and performance then it becomes convenient.

So, mean effective pressure is not only the concept that we are writing here because that is only to eliminate the spatio temporal change in pressure that is there always inside the cylinder to get rid out of that issue. But also this parameter is an important parameter for comparing the performance of the engine as well as for comparing the design of the engine instead of torque and power.

So, also here discussed that rather we could write this mean effective pressure in its different form. So, it can be break mean effective pressure (bmep), we also can write indicated mean effective pressure (imep), we also can write frictional mean effective pressure (fmep). Now what we could write that the work which is available inside the cylinder is not the work which is there at the crankshaft because of several issues frictional loss as well as the power or work needed to run several devices for the parasitic loads that we have discussed.

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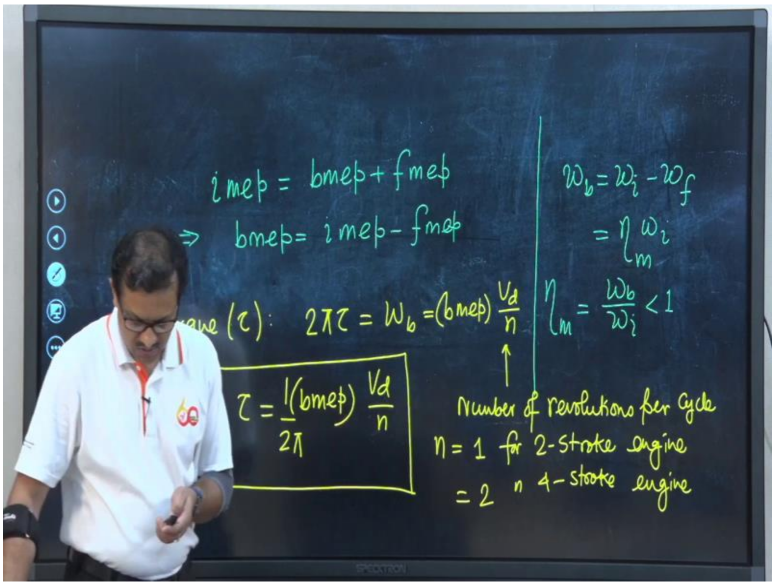

And we have seen that $imep = bmep + fmep \rightarrow bmep = imep - fmep$. This is similar to $w_b = w_i - w_f$. And from there we could write that this quantity w_b is less than w_i. So, we can write one factor multiplied by w_i and that factor is known as mechanical efficiency. So, this mechanical efficiency $\eta_m = w_b/w_i$ and it is always less than one.

So, this is what we have discussed in the last class and we could write it. So, we had also discussed the indicator diagram in the last class and we are saying that about the atmospheric pressure line there are 2 different Loops, the upper Loop that that gives us the positive work and that is the work we are getting while the lower loop or lower part is the negative work.

So, that is the work that we need to supply to the engine cylinder. So, the net work that we will get is that positive minus negative. So, if someone would like to calculate what is the work output from the engine he or she needs to draw the indicator diagram and from there he or she can calculate the net work available from the engine.

But instead what is done some parameters are introduced to measure the work which is available at the crankshaft. So, today we shall discuss about what that parameter is, now if we write an important parameter that you all have studied that is torque,τ. So, this is basically an indicator, as such I should say torque is a good indicator of an engines capability or ability to do work.

So, torque is the force acting at a moment distance and this torque is related to the work, $2\pi\tau = W_b$. now you may ask me a question why we are writing brake work; so, as I said you few minutes back that if someone would like to calculate or measure the work output from the engine definitely he or she must be taking an effort to draw the indicator diagram but it is not a practical viable case. So, we need to look for other options from which we can calculate the work output.

So, basically if we can measure torque, then we can get a fair estimate about the work that is being produced. And question is why it is break I think you have studied about the dynamometers. So, basically dynamometer are used to measure some quantity and that dynamometer measures that quantity at the crankshaft.

What we have discussed in the last class, the work which is available at the crankshaft is the brake work. So, since the dynamometer can only measure the quantity torque at the crankshaft. So, definitely that torque can be related with the work which is available at the crankshaft and that is why it is break work. So, I had written the torque which is defined as the force acting at a moment distance and which can be related to the work through this relation but I have used this suffix b. So, that is the brake work. Why it is brake work because dynamometer which should be used to measure torque at the crankshaft, only brake work is available. So, we can write this is brake work.

So, now $2\pi\tau = W_b = (bmep)V_d/n$. So, because we are writing not in specific form. So, n is number of revolutions per cycle. So, this is the expression of torque. So, you can write the torque $\tau = (1/2\pi)(bmep)V_d/n$. This n is one for 2 stroke cycles engine, this is equal to 2 for 4 stroke cycles engine. Because for the first stroke cycle engines we have seen there are 2 revolutions per cycle of the crankshaft.

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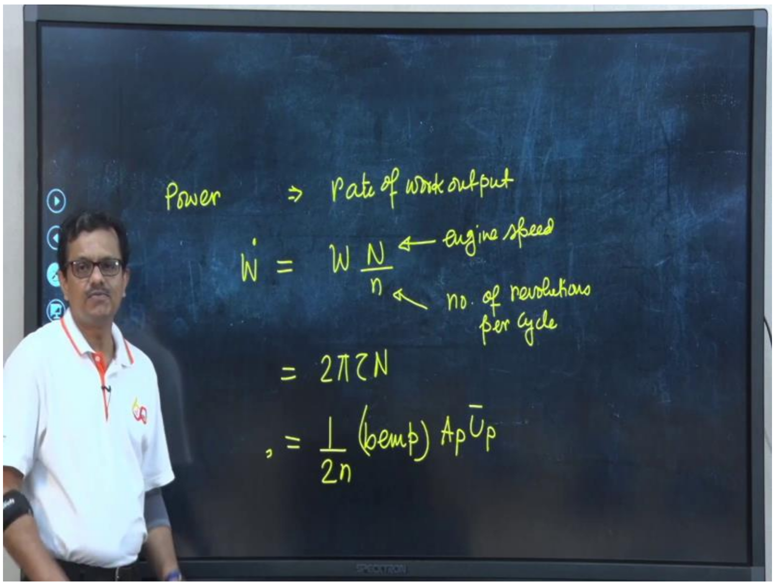

Next is another important parameter which will be mostly used to compare the engine performance that is power. So, if we can calculate work done by dynamometer which is used to measure torque which is connected to the shaft of the engine, from there we can get the power. Power is rate of work output.

So, this is $\dot{W} = W(N/n)$ where N is engine speed and n is number of revolutions per cycle. So, we also can write in different form that is $2\pi\tau N$ in terms of torque because essentially we are writing rate of work output.

So, if we can write this power in terms of brake mean effective pressure then $\dot{W} =.= \left(\frac{1}{2n}\right)(bmep)A_p\overline{U}_p$. So, $A_p$is the piston area and $\overline{U}_p$ is the average piston speed. So, that will give the displacement volume because we are trying to express this quantity in the rate form.

Now issue is we have expressed the form of torque, power and all these are very important to determine the engine performance. So, when you are talking about engine performance you know that we are getting something at the cost of something else. So, we are getting work output at the cost of some input energy.

So, definitely though we are trying to calculate work output or power by using all these Expressions definitely we need to measure the torque which is available at the crank shaft using a dynamometer but this quantities are measured and we can predict but when you are trying to compare the performance we again need to look at the input energy. So, basically this is the amount of work which you are getting from the engine at the cost of what. So, basically we also need to look at what is the input energy to the engine and to express that we also need to define a few parameters.

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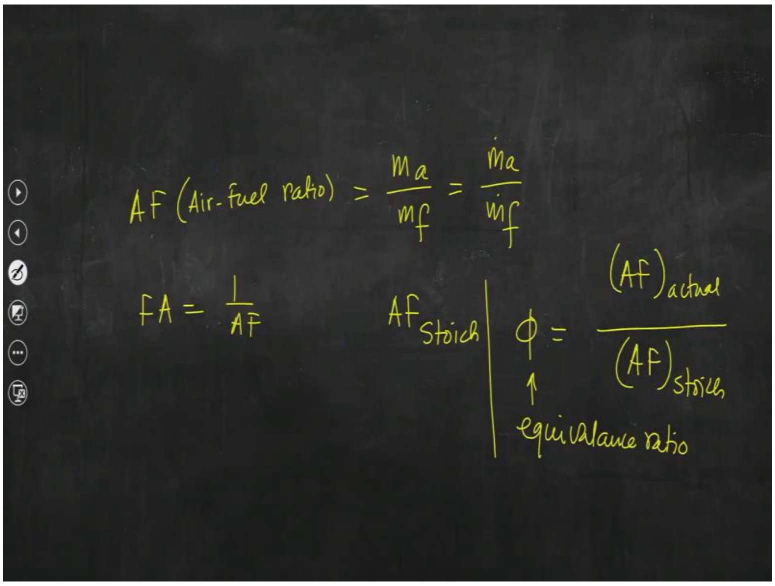

We have already discussed about the mass flow rate of fuel and mass flow rate of air because fuel alone cannot be used to run engine. So, for the transportation vehicles fuel itself cannot ensure that the combustion would be completed. So, we had seen that we also need to supply adequate amount of air. So, we have discussed about air fuel ratio. So, that is air fuel ratio.

$$AF = \frac{m_a}{m_f} = \frac{\dot{m}_a}{\dot{m}_f}$$

So, kg of air by kg of fuel or we can write mass flow rate of air by mass flow rate of fuel. So, So, this is very important because fuel alone cannot ensure that the combustion will takes place or combustion will be completed. So, we need to supply adequate amount of air as well.

So, what would be fuel-air ratio. So, that is 1/AF why I am trying to discuss all this parameters because as I told you that we can get work output from a engine and that amount of work is obtained at the cost of some input energy and if what is that input energy because you are supplying fuel. So, the chemical energy that is remaining stored within the fuel that will be utilized to get the mechanical energy.

So, what is the amount of fuel to be supplied to the engine that is air fuel ratio and we have seen that there is a chemically correct air fuel ratio that is the stoichiometric air fuel ratio. So, for a given engine if we can supply air fuel is stoichiometric, we can ensure that the combustion would be completed efficiently and will be getting some work output.

Issue is always transportation vehicle will not run in its design condition. So, either maybe we need to go for power zone that is deviation from the cruising zone also depending on the weather condition. The air flow ratio that would be required to run the engine at that condition would be somewhat different that the air fuel ratio stoichiometric.

So, depending on the situation whether we need to run engine in the power zone or if we need to run the engine in a space where ambient conditions are not same then the air flow ratio that would be required to run the engine at that prevailing condition will not be equal to the airflow ratio stoichiometric. So, this air fuel ratio actual will be somehow different than the airflow ratio stoichiometric.

So, ratio of these 2 quantities is also known as equivalence ratio, ϕ. So, the significance of this ratio is that this gives us a clue about the deviation of the air fuel ratio from stoichiometric quantities. So, basically the actual Air fuel ratio that is needed to run the engine at any condition from its stoichiometric condition is obtained by knowing the equivalence ratio because all these quantities are related to the performance of the internal combustion engine.

So, this is the equivalence ratio now another important quantity which is very often used is known as specific fuel consumption.

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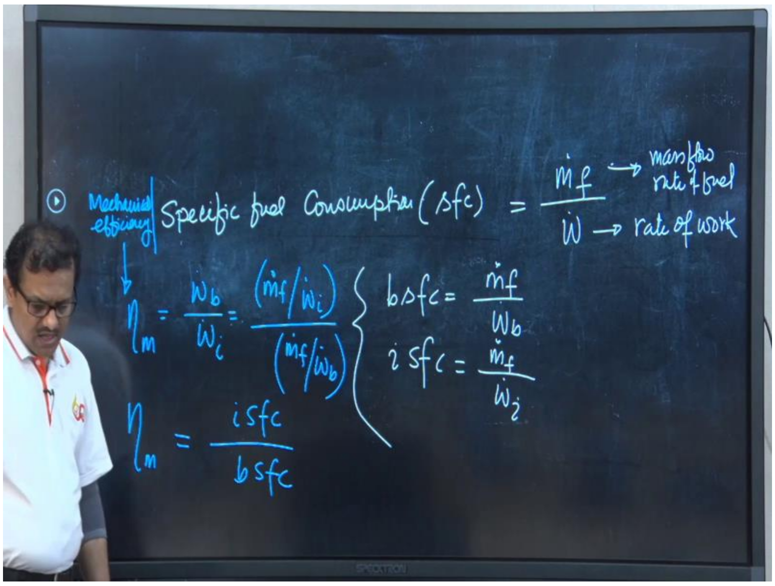

So, that is sfc or specific fuel consumption. So, basically this is a performance analysis parameter, it is defined as $\dot{m}_f/W_b$. So, why I had written break because eventually the work we are getting from the engine is the brake work. So, the amount of fuel that we are supplying, the actual amount of work will be produced inside the cylinder is higher than this break but we are actually getting W_b. So, is the generic form is $\dot{m}_f/W$.

$$bsfc = \frac{\dot{m}_f}{W_b};\ isfc = \frac{\dot{m}_f}{W_i}$$

So, if we are looking at the brake power then it will be brake specific fuel consumption while if we look at the indicated power then it will be indicated fuel consumption. So, now let me tell that if we can measure only the brake work, then again we will be considering the brake fuel specific consumption because we are getting brake work and to calculate the brake work but for the calculation if we consider indicated work then the fuel consumption would be something else because this is much more higher than W_b. So, if we consider indicated work or indicated power then specific fuel consumption would be less.

So, we cannot say that a engine or any transportation vehicle which is having lesser specific fuel consumption and would be giving this much amount of work. So, if we say then we have to say correctly that if that is the amount of work which is available at the break then break specific fill consumption should be little higher. So, we cannot say the brake work which should be available at the crankshaft at the cost of the indicated specific fuel consumption.

Because the specific fuel consumption considering brake work should be little higher than the specific fuel consumption obtained using the indicated work. So, again it is similar to what we have discussed like brake mean effective pressure and indicated mean effective pressure. So, we can write mechanical efficiency as brake work divide by indicated work. So, we also can write in the rate form.

$$\eta_m = \frac{\dot{W}_b}{\dot{W}_i} = \frac{\left(\frac{\dot{m}_f}{W_i}\right)}{\left(\frac{\dot{m}_f}{W_b}\right)} = \frac{isfc}{bsfc}$$

So, again we could write mechanical efficiency in terms of the specific fuel consumption. So, you can see that the indicator specific fuel consumption is always less than the break specific fuel consumption. So, we have discussed today that is the torque and brake specific fill consumption and also the power.

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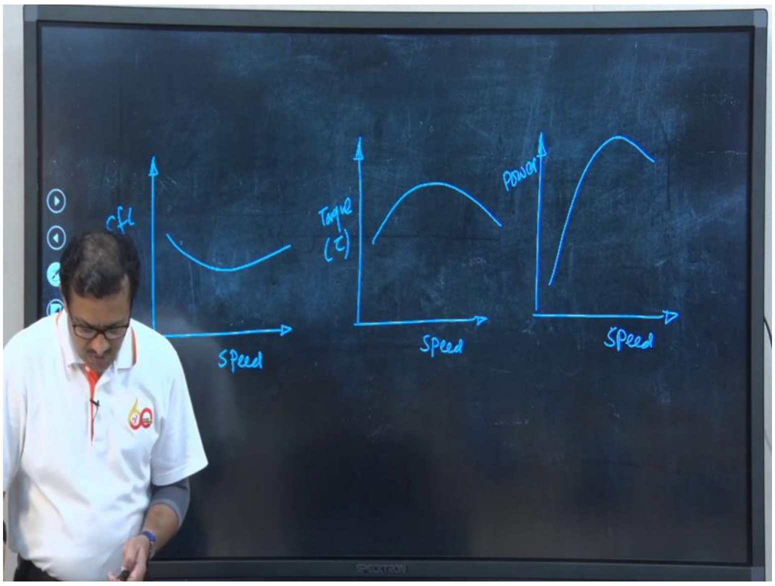

So, if we try to plot all these quantities with engine speed. So, this is speed versus specific fuel consumption, torque, and power. So, variation of torque is reverse of the specific fuel consumption. So, we could establish the expression of specific fuel consumption, torque and power. So, issue is why the variations are like this if we increase speed sfc decreases reaches at its minimum and then again increases.

If we increase speed torque increases and then finally becomes maximum and again decreases. So, the physical reasoning behind the nature of these curves will explain when we shall solve any numerical problem whether it is for CI or SI.

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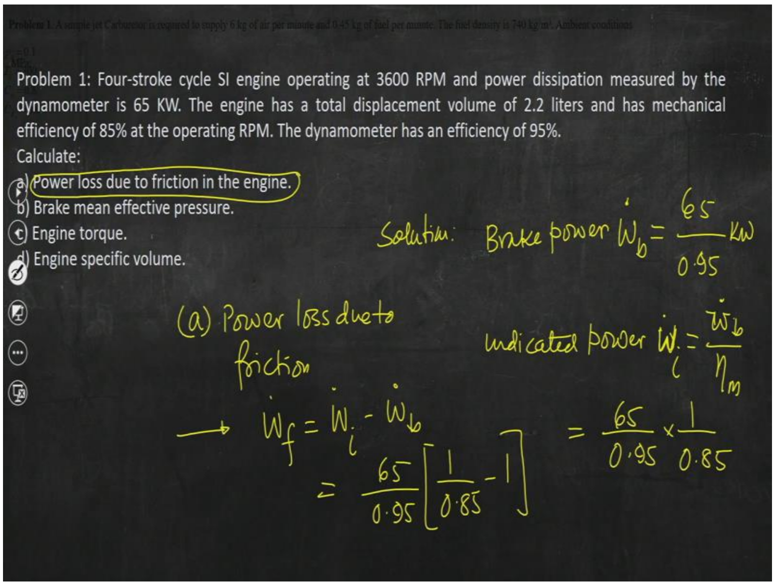

So, the problem statement is a 4 stroke cycle SI engine operating at 3600 RPM and power dissipation measured by the dynamometer is 65 kilowatt the engine has a total displacement volume of 2.2 liters and has mechanical efficiency of 85% at the operating RPM.

The dynamometer has an efficiency of 95% we need to calculate power loss due to friction in the engine, brake mean effective pressure, engine torque and engine specific volume. So, whatever we have discussed in today's class just by considering this numerical example if we solve it that will give us enough confidence to solve several other numerical problems and at least that will help us to understand the concept that we have discussed.

So, let us solve it. So, as I told you the dynamometer is used to measure the dissipation. So, basically the torque which is produced when the shaft is rotating. So, brake power we can write $\dot{W}_b = 65/0.95$ as dynamometer itself has efficiency of 95 percent. So, we also can calculate indicated power $\dot{W}_i = \dot{W}_b/\eta_m$. So, $\dot{W}_i = \dot{W}_b/0.85$.

So, power loss due to friction in the engine is $\dot{W}_f = \dot{W}_i - \dot{W}_b$

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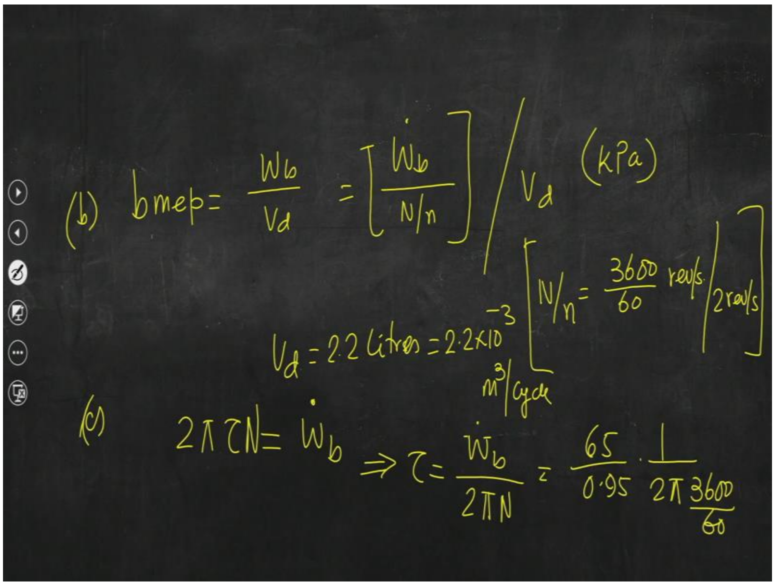

Now, break mean effective pressure

$$bmep = \frac{W_b}{V_d} = \frac{\left[\frac{\dot{W}_b}{\left(\frac{N}{n}\right)}\right]}{V_d}\ kPa\ \ where \frac{N}{n} = \frac{\frac{3600}{60}\frac{rev}{s}}{2\frac{rev}{s}};\ \ V_d = 2.2\,l = 2.2 \times 10^{-3} m^3/cycle$$

Because it is 4 stroke cycle SI engine. So, n is 2 as there are 2 revolution per cycle.

Now, torque

$$2\pi\tau N = \dot{W}_b \rightarrow \tau = \frac{\dot{W}_b}{2\pi N}$$

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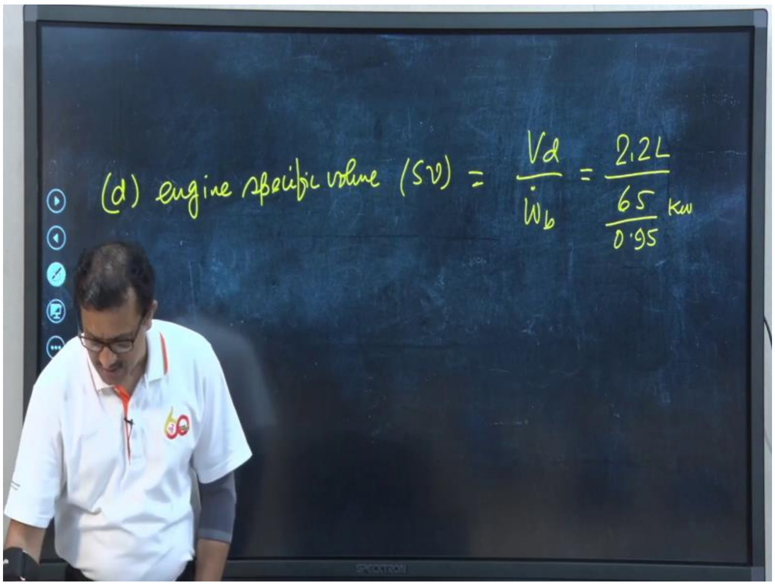

So, now engine specific volume

$$sv = \frac{V_d}{\dot{W}_b} \;\; l/kw$$

So, per kilowatt what is the displacement volume needed that is the specific engine specific volume. So, per kilowatt of that brake work what is the requirement of the kind of displacement volume. So, that is the engine specific volume. So, to summarize today's discussion we have discussed about several parameters those are directly you know related to the engine performance those are very often used to measure the performance of the internal combustion engine, we have tried to express their mathematical forms. And finally we have tried to express their variation with the change in speed.

Though we did not discuss about the nature of the curve and that part we will discuss in one of the next classes. And finally you have solved one numerical problems and by solving that problem we have understood how we can calculate several performance measuring parameters knowing certain information of the internal combustion engine. So, with this I stop here today and we shall continue our discussion in the next class, thank you.