Introduction to Airbreathing Propulsion
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Lecture – 20
Piston Engines and Propellers (Contd.,)

Okay so let us continue the discussion on this Otto cycle analysis and we have looked at the thermal efficiency and the other things for the ideal cycle and also talked about when the efficiency actually differs in the real cycle.

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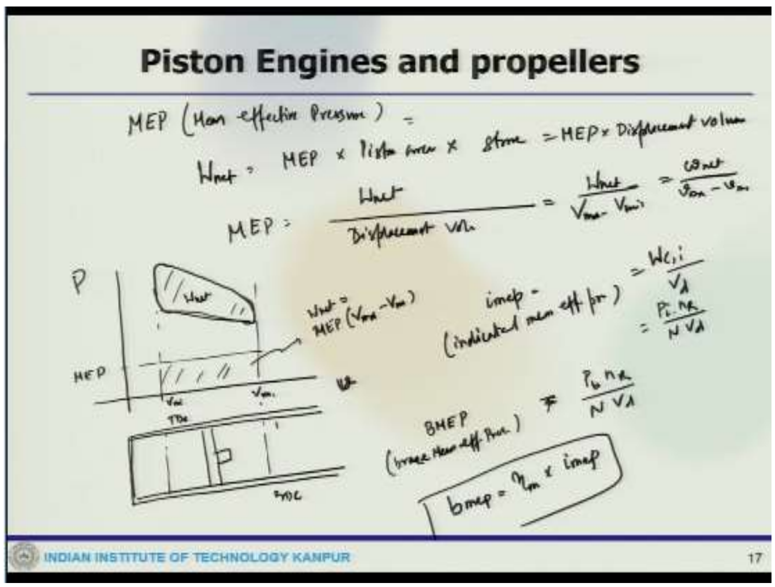

Now we are discussing about the mean effective pressure and then we can do search which could be imep that could be defined as

$$imep = \frac{W_{ci}}{V_d} = \frac{P_i n_R}{N V_d}$$

Now if brake work is used then brake mean effective pressure which is called brake mean effective pressure which could be written as also like

$$BMEP = \frac{P_b n_R}{N V_d}$$

So both mean effective pressure are related like

$$bmep = \eta_m * imep$$

So they are connected with the mechanical efficiency of the shaft.

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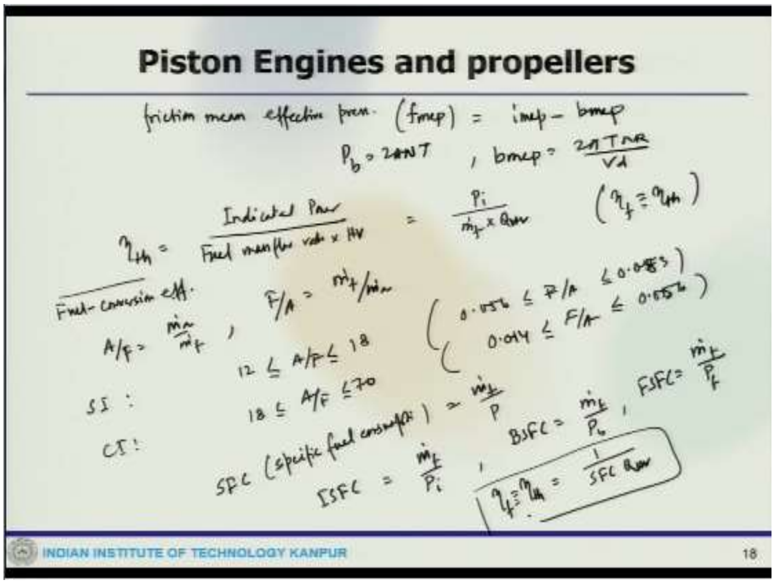

Now also we can define the friction mean effective pressure. So like

$$fmep = imep - bmep$$

So we have

$$P_b = 2\pi NT$$

and

$$bmep = \frac{2\pi NTn_R}{V_d}$$

so with that also we can have some other, other definition of the thermal efficiency of the Otto cycle. Let us say we can have we can define the thermal efficiency also and define as the fuel conversion efficiency like; then we can write

$$\eta_{th} = \frac{indicated\ power}{Fuel\ mass\ flow\ rate * HV} = \frac{P_i}{\dot{m}_f Q_{HV}}$$

So this is what one can write that fuel conversion efficiency. Now also we have air fuel ratio or fuel air ratio. Now if you say A/F that is air fuel ratio; if you say F/A that is fuel air ratio. Now for normal operating range SI engines or the gasoline engines have an air fuel ratio of something around 8, so the fuel air ratio would be 0.056 to 0.083 or CI engine, this is typically 18 above to 70 which would be 0.014 to 0.056.

Now also here specific fuel consumption, SFC which is Specific Fuel Consumption which is

$$SFC = \frac{\dot{m}_f}{P}$$

Now similarly we can have ISFC, this is indicated specific fuel consumption which is

$$ISFC = \frac{\dot{m}_f}{P_i}$$

We can have brake specific fuel consumption which could be

$$BSFC = \frac{\dot{m}_f}{P_b}$$

We could have frictional specific fuel consumption which is

$$FSFC = \frac{\dot{m}_f}{P_f}$$

So what we can then write this guy the fuel conversion efficiency is like; so η which is a fuel conversion efficiency, we can write like

$$\eta_f = \eta_{th} = \frac{1}{SFC * Q_{HV}}$$

okay. So the specific fuel consumption is inversely proportional to the thermal efficiency or normal hydrocarbon fuel, okay. Now there are different range of fuels which can be used and their different values of kind of their efficiency level.

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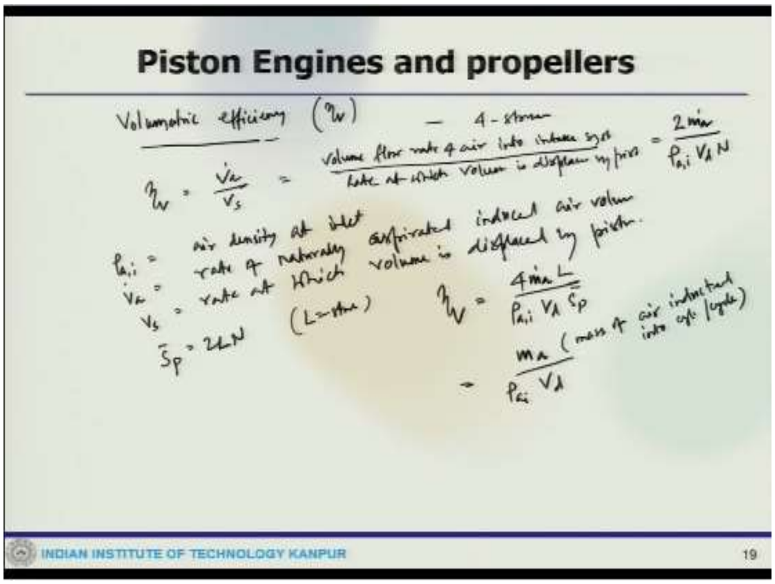

Now we will move to find out the other parameters like volumetric efficiency, so which is η_V. Now volumetric efficiency is one that used only in four-stroke engine, so this is used for four-stroke which have a distinct induction process. And this gives an measure of the; for the effectiveness of engines induction process as the intake system like the air filter, carburetor, intake manifold or intake valve that restricts the amount of the intake amount of the air inducted to the engine.

So this can be defined as that

$$\eta_V = \frac{\dot{V}_a}{V_s}$$

which is the volume flow rate of the air into the intake system, so this is volume flow rate of air into intake system to the; so this is a; divided by the rate at which volume is displaced by piston. So this one can write

$$\eta_V = \frac{2\dot{m}_a}{\rho_{ai} V_d N}$$

where ρ_{ai} is the air density at Inlet, $\dot{V}_a$ is the rate of naturally aspirated induced air volume, V_s is the rate at which volume is displaced by piston.

Since this piston speed is defined so

$$\bar{S}_p = 2LN$$

where L is the stroke then we can write

$$\eta_V = \frac{2\dot{m}_a L}{\rho_{ai} V_d \bar{S}_p}$$

so that sort, this is a; where m is the mass of the air inducted in the cylinder per cycle, okay. So that is what we can so here we can write m a and this is the mass of air inducted into cylinder or cycle, so that sort, you get the volumetric efficiency.

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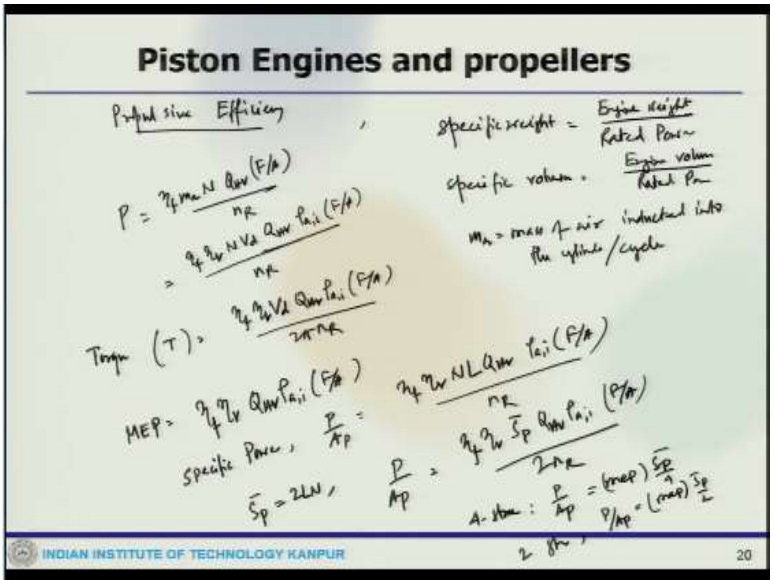

Now we can get propulsive efficiency. So this is the piston engine is coupled to a propeller to furnish the forwarding thrust for the propulsion efficiency also could be defined. So the now one can have some definition like engine specific weight and specific volume of the engine specific weight which is the engine weight divided by rated power and you can have specific volume which is the engine volume divided by rated power.

Relationship between these performance parameters we can establish. Now the; we can write

$$P = \frac{\eta_f \dot{m}_a N Q_{HV} (F/A)}{n_R}$$

so which is

$$P = \frac{\eta_f \eta_V V_d Q_{HV} \rho_{ai} (F/A)}{n_R}$$

so this is the same m_a one can use that this is m_a is the mass of air inducted into the cylinder per cycle.

So then the torque where we get

$$P = \frac{\eta_f \eta_V N V_d Q_{HV} \rho_{ai} (F/A)}{2\pi n_R}$$

and mean effective pressure there would be

$$MEP = \eta_f \eta_V Q_{HV} \rho_{ai} (F/A)$$

Now the power part piston area often called specific power. So the specific power is defined as

$$Specific\ power = \frac{P}{A_p} = \frac{\eta_f \eta_V N L Q_{HV} \rho_{ai} (F/A)}{n_R}$$

And introducing the mean piston speed which

$$\bar{S}_p = 2LN$$

$$\frac{P}{A_p} = \frac{\eta_f \eta_V \bar{S}_p Q_{HV} \rho_{ai} (F/A)}{2n_R}$$

So typically for four-stroke engine this is

$$\frac{P}{A_p} = (mep)\frac{\bar{S}_p}{4}$$

and two-stroke this

$$\frac{P}{A_p} = (mep)\frac{\bar{S}_p}{2}$$

So these are the typical values of this power. Now we can move to some two-stroke engine or two-stroke Otto cycle engine.

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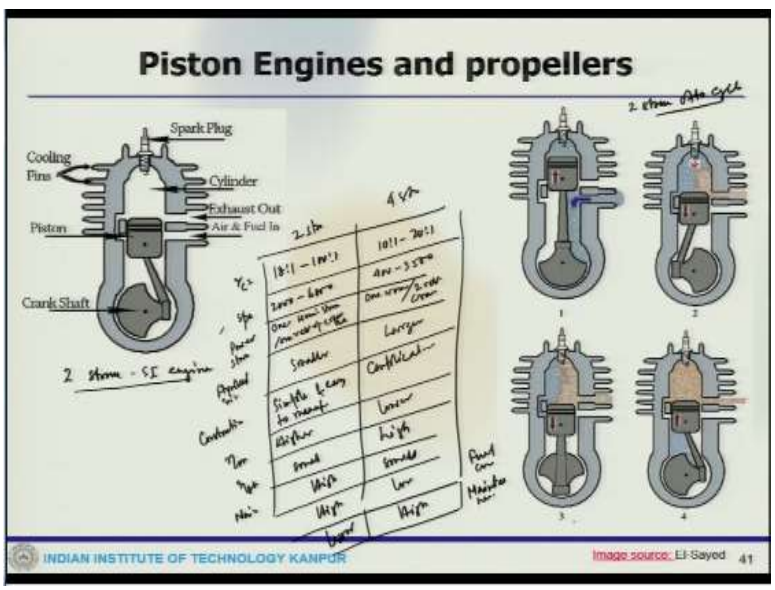

So let us see some; this is a typical picture of two-stroke engine where this is a two-stroke SI engine what you can see and this is; this is the cycle, two-stroke Otto cycle. Now what it talks about that engine has very small two-stroke engine. This is using ultralight aircraft similar to four-stroke engine; also this has some cylinder piston crankshaft connecting rod so these are having all these.

So the petrol engine uses the spark plug and the diesel engine replaces the spark plug with the fuel injector, okay. And this is the typical cut section of the engine here and this is the cycle of the engine so where you can see a fresh charge of fuel air mixture enters and then you have like piston uncovers here and then uncover the intake port while moving upward. Then there is already a fuel air mixture which is being compressed in the cylinder so which are head above the piston and the top of the compression stroke the explosion takes place due to the spark plug.

Now when the piston moves downwards here in the third stroke it slowly uncovers the exhaust port. Now the exhaust flow takes place when the piston again moves back. So this is shows you some of the idea about that these things, now we can compare some two-stroke and four-stroke engines like simple comparison of we can have let us say two-stroke and four-stroke, so one could be the compression ratio.

So let us say, here this is typically 18:1 to 100:1. This we are talking about compression ratio and this case it is 10:1 to 20:1. Then speed this case this is 2000 to 6000 then this is 400 to 3500. And then we can have power stroke, so this is one working stroke per one revolution of the crankshaft; the one working stroke per one revolution of crankshaft. And this is one working stroke for two revolution of crankshaft, okay. So flywheel size; this is smaller, this is larger.

Then you have construction; this is simpler and easy to manufacturer; manufacture, this is complicated. Mechanical efficiency; this is higher due to few moving parts, this is lower. Thermal efficiency; this is small, this is quite high. Noise; this case it is high, this case also small. Fuel consumption; this case it is high, this case low. Finally, the maintenance; this is high maintenance, this is low maintenance. So these are some of this comparison that you can think about.

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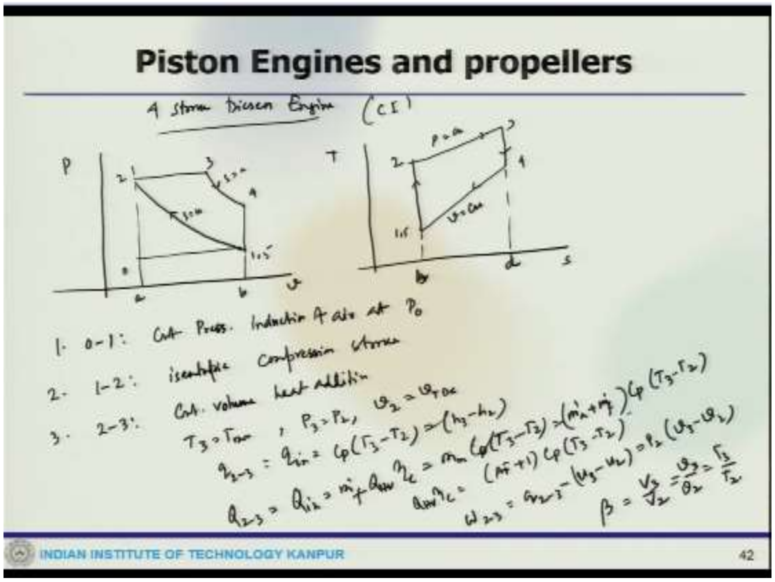

Now with that we will go to now four-stroke diesel engine discussion or the compression CI engine discussion. So this is a compression ignition kind of reciprocating engine. So this was first proposed by Rudolf Diesel in 1890s that was very similar to the SI engine which was already discussed. So here the air is compressed to a limit where then the fuel is injected and the combustion takes place.

So if we put the diagram for this again like this is P and V diagram, so that sort from 0 to 1 then it goes, it comes back 2, 3, 4, 5. So this case it is constant, this case it is constant and this is A, this is B. Similarly, if you put that thing back in TS diagram, so this is 1, 5 then it goes up, comes down, comes here; this is 2, this is 3, 4, this is; sorry this is B, this is A, so here P constant and V constant.

So now here different process that we can define, now the thermodynamic process like this case also 0 to 1 is constant pressure, induction of air at ambient pressure p_0, so here the intake valve is open and the exhaust valve is closed. And now second 1 to 2, this is isentropic compression stroke, so here the both the valves are closed then third 2 to 3 this is constant volume heat addition process that means the combustion takes place here, so here we get

$$T_3 = T_{max}$$

$$p_3 = p_2$$

$$V_2 = V_{TDC}$$

$$q_{in} = q_{2-3} = C_p(T_3 - T_2) = h_3 - h_2$$

$$Q_{2-3} = Q_{in} = \dot{m}_f Q_{HV} \eta_c = \dot{m}_m C_p(T_3 - T_2)$$

$$Q_{2-3} = Q_{in} = (\dot{m}_f + \dot{m}_a) C_p(T_3 - T_2)$$

$$Q_{HV} \eta_c = (AF + 1) C_p(T_3 - T_2)$$

So the specific work would be

$$w_{2-3} = q_{2-3} - (u_3 - u_2) = p_2(v_3 - v_2)$$

Now there is a cutoff ratio which is called β here that is defined as

$$\beta = \frac{V_3}{V_2} = \frac{v_3}{v_2} = \frac{T_3}{T_2}$$

okay.

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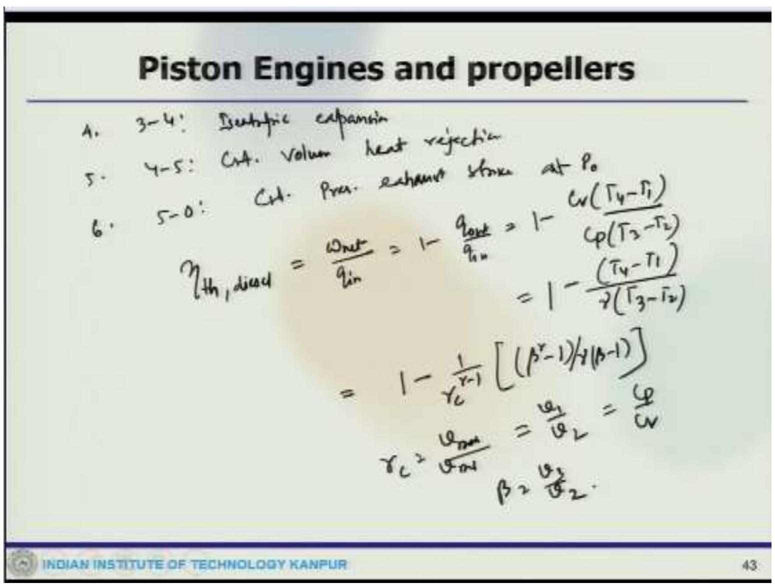

So now we will go to process 3 to 4, this is again isentropic process isentropic expansion stroke or the power stroke, all valves are closed then process 4 to 5, this is again constant volume heat rejection process. So here the exhaust valve is open and intake valve is closed. And then we have 5 to 0 which is constant pressure exhaust stroke at p_0 which is ambient. So now the piston then executes at an engine stroke in which the burned gases are poured into the cylinder through the open exhaust valve.

So the thermal efficiency that for diesel engine we can get

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)}$$

We can write

$$\eta_{th} = 1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)}$$

So we can do little bit of rearrangement and then what we can write, this could be

$$\eta_{th} = 1 - \frac{1}{r_c^{\gamma-1}} \frac{\beta^{\gamma} - 1}{\gamma(\beta - 1)}$$

so where

$$r_c = \frac{V_{max}}{V_{min}} = \frac{v_1}{v_2} = \frac{C_p}{C_v}$$

$$\beta = \frac{V_3}{V_2}$$

So this is what we get the thermal efficiency of the cycle and we will stop here and continue the discussion in the next lecture.