Lecture 9

3rd Semester M Tech. Mechanical Systems Design

Mechanical Engineering Department

Subject: Advanced Engine Design

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Topic: Design Of A Turbocharged Diesel Engine For A Passenger Car

A Compression Ignition Engine Design

Objective: Estimate Engine Displacement Volume Required – 05-10-2020

Numerical Example:

Q1 Design a Turbocharged Diesel Engine For A Passenger Car.

The engine is to have a rated power of 100 KW at 4200 rpm.

Solution:

The engine has to be designed for a passenger car run by diesel fuel
This is a C.I engine based Passenger Car

Given Data:

Rated Power = 100 KW

Rated Speed = 4200 rpm

The above Rated Speed suits a diesel passenger car engine for the following reasons:

Consider the equation for **Newton's Second Law of Motion** for a reciprocating **piston**.

F = m*a

Reason 1

Lean Operation of CI engines.

A/F = 18 - 70

1. For pollution control the CI engines are operated lean.
2. So CI engines have larger displacement volume as compared to SI engines for same power.
3. Larger displacement volume will make the geometrical size and therefore the mass of the piston for CI engine larger.
4. Assuming that the force F acting on the piston is same for both the SI and CI engines.
5. Since the term mass m of the piston on the right hand side of the Newton's second law of motion has a higher value for CI engines, so the second term acceleration, a should be brought down.
6. So the crankshaft rotational speed N is decreased.

Note :

Inertia is associated with mass only. It means resistance to motion offered by the mass m of the piston against the force F acting on the piston.
At this point we are not talking of the combustion based piston motion.
Rather we are talking about the force F and the corresponding resistance offered by a mass m of the piston to this force F.
Such analysis can be done by using external motors driving the crankshaft and therefore the piston moves up and down without combustion In the engine cylinder.

Reason 2

Lower B/L ratio for CI engines

7. The B/L ratio for CI engines is lower than that for SI engines.
8. Therefore the CI engines have longer stroke than SI engines to maintain a high combustion efficiency with heterogeneous combustion.
9. Longer stroke L of the cylinder will increase the value of acceleration or deceleration a of the piston between TC and BC for the same crankshaft rotational speed N.
10. **In order to keep the inertia force F same, the crankshaft rotational speed N needs to be brought down.**

Therefore crankshaft rotational speed was chosen as:

N = 4200 rpm

We Know - The best possible Brake Specific Fuel Consumption for C.I engine = 200 g/KWh

Let

BSFC = 235 g/KWh

Reasons –

Refer the chapter: characteristics Performance Curves of C I engines under variable speed operation

1. From the curves we see that the best possible BSFC or minimum BSFC is towards the speed for maximum torque
2. We get best possible combustion efficiency at this engine speed which minimizes the fuel consumption.
3. On the same curve for BSFC when we go towards the idle speed or towards the rated speed for maximum power – the BSFC increases in both directions with a corresponding drop in combustion efficiency
4. The BSFC for the turbocharged diesel engine is lower than that of a naturally aspirated diesel engine since approximately 9.6% energy is recovered from the exhaust gas by incorporating the turbine of a turbocharger. This decreases the fuel consumption per unit energy output.

Let

Volumetric Efficiency = 91 percent

Reason:

1. The intake manifold design for CI engines is more suited for maximizing the volumetric efficiency of the engines. The intake manifold for CI engines is tuned better than the SI engines.
2. The valve train design is better. The valve overlap period can be made longer for CI engines as compared to SI engines. This will help to improve the scavenging efficiency of CI engines associated with their exhaust process.
3. Further a longer valve overlap period for CI engines does not result in the short circuit based fuel loss as only air is induced into the cylinder.

By using the equation for the definition of BSFC

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

Where

$\dot{m}_f$ = mass flow rate of fuel

P = Power developed by the engine

Or

$\frac{\dot{m}_f}{P}$ = 235 g/KWh

Power = 100 KW

(Decided as per engine application and comparison with previous example)

Therefore substituting above:

$\dot{m}_f$ = 235 g/KWh * 100 KW

$\dot{m}_f$ = 23,500 g/h

$\dot{m}_f$ = 0.39 Kg/min

Mass flow rate of fuel = 0.39 Kg/min

The above computed data will help us to design the fuel supply system

Let

A/F ratio = 23:1

Reasons:

1. The Operating Range of A/F ratio for C.I engines is (18 to 70)
2. The Stoichiometric A/F ratio for Diesel fuel = 14.5
3. The diesel engines are operated lean to minimize the soot emissions from diesel engines. However this does not decrease the power output from the engine.
4. **Since we design the CI engine for minimum soot emissions with same power so A/F =23 will suit**

A/F = $\frac{\dot{m}_a}{\dot{m}_f}$

Where

$\dot{m}_a$ = mass flow rate of air
$\dot{m}_f$ = mass flow rate of fuel

From the above equation:

$\dot{m}_a$ = A/F * $\dot{m}_f$
$\dot{m}_a$ = 23 * 0.39 = 8.97 Kg/min

Mass flow rate of Air = 8.97 Kg/min
The Above computed data will help us in the design of air supply system

Now by using the equation for volumetric efficiency we can calculate engine displacement Volume required.

Volumetric Efficiency is given by the equation:

$\eta v = \frac{2 * \dot{m}_a}{\rho_{a,i} V_d N}$

Where

$\dot{m}_a$ = Actual mass flow rate of air
$\dot{m}_a$ = 8.97 Kg/min
$\rho_{a,i}$ = ambient inlet air density
$\rho_{a,i}$ = 1.18 Kg/m^3
$\rho_{a,p}$ = density of air after compression by a compressor at intake port of the engine.
$\rho_{a,p}$ = 1.98 Kg/m^3
Volumetric efficiency of the engine without a compressor = 0.91 = 91%
Volumetric efficiency of the engine with a compressor = 1.67 = 167%
V_d = Engine displacement volume ---- ?

Substituting the values in the equation for volumetric efficiency we get:

$V_d = 0.00237\ m^3$

$V_d = 2370$ cc

V_d = 2400 cc
Displacement Volume Required = 2.4 liters

Conclusions:

To design a naturally aspirated petrol engine for Rated Power of 100 KW at the rated speed of 5500 rpm
V_d = 2200 cc

To design a naturally aspirated diesel engine for the rated power of 100 KW at the suited rated speed of 4200 rpm with lean combustion for the control of soot emissions
V_d = 4400cc

To design a Turbo-charged diesel engine for the rated power of 100 KW at the suited rated speed of 4200 rpm with lean combustion for the control of soot emissions
V_d = 2400 cc

This type of turbocharged diesel engine needs almost same space in the bonnet of a car as that demanded by a naturally aspirated petrol engine.
This turbo-charged diesel engine technology makes it competitive for the available alternative petrol engine technology for choosing a prime mover for a passenger car.
However some space will be taken by the turbocharger fitted to the engine.
Further the cost of a turbocharger has to be included in the total cost of the engine or the passenger car.
The turbocharger cost is a one time cost and contributes to about 3% of the total cost of the passenger car.
Since the operating cost of diesel engines is less, the additional initial cost is recoverable in the case of commercial turbocharged diesel engine based passenger car.

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Text Book:
Vehicular Engine Design
By Kevin L. Hoag
Published By: SAE International USA