Lecture 11

3rd Semester M Tech. Mechanical Systems Design

Mechanical Engineering Department

Subject: Advanced Engine Design

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Topic: Determination Of Number Of Cylinders

Objective: Division of the Estimated Total Engine Displacement Volume Into A Multi-Cylinder Engine Based Smaller Cylinder Displacement Volumes – 08-10-2020

Factors that govern the possible **division of** a total engine **displacement volume** into smaller volume Based multi-cylinder engine are:

1. Cost and Complexity
2. Reciprocating mass and required engine speed
3. Surface to volume ratio
4. Pumping losses
5. Packaging – Layout or Possible Arrangement of The Cylinders In A Multi-cylinder Engine.
6. Balancing of mechanical forces

1. Cost and Complexity

Cost and complexity certainly lead the engineer to the lowest practical number of cylinders for any given engine.

In general

Lower number of cylinders – less production and manufacturing cost
Lower number of cylinders – less complex engine assembly

Reasons:

(a) The quantities of components or parts in an engine are directly multiplied by the number of cylinders.
(b) So the fewer the cylinders, the lower the production and manufacturing cost, cost of materials and assembly.

Example:

Table 1: The Number Of Components of Single Cylinder And Multi-Cylinder Engines.

Engine Classification	**Number of Crankshaft**	Number of Cylinders	Number of Pistons	Number of connecting rods	Number of Valves (minimum)	Number of piston rings
Single Cylinder Engine	**1**	1	1	1	2	3
Two Cylinder Engine	**1**	2	2	2	4	6
Three Cylinder Engine	**1**	3	3	3	6	9
Four Cylinder Engine	**1**	4	4	4	8	12

Table 2: The Number Of Components of Single Cylinder And Multi-Cylinder Engines.

Engine Classification	Number of small end bearings	Number of big end bearings	Number of Main Bearings	Number of spark plugs	Number of high tension cords	Number of fuel Injectors
Single Cylinder Engine	1	1	2	1	1	1
Two Cylinder Engine	2	2	3	2	2	2
Three Cylinder Engine	3	3	4	3	3	3
Four Cylinder Engine	4	4	5	4	4	4

2. Reciprocating Mass and required engine speed.

Using the Newton's second law of motion

F = m*a

F = force acting on the piston ---- (A **manageable force** per cylinder)

S.I engines

A spark plug is fitted in the centre of each engine cylinder.
The S.I engines undergo homogeneous combustion.
A spark is given in the spark plug for each engine cycle. After pre-flame reactions, the flame gets

developed and then propagates in all directions in the combustion chamber of the engine.
The flame speed depends on the type of fuel being used and also on engine design and operating parameters.
For any **crankshaft rotational speed**, the corresponding time available for one complete cycle and then for each combustion process in a cycle can be computed.
The time available for the combustion process from the crankshaft rotational speed point of view should meet the time required for combustion process in the combustion chamber on the basis of initiation of spark, pre-flame reactions, flame development and flame propagation. The minimum and maximum possible flame speed will decide the suitability of the bore of each cylinder.
This will decide the combustion efficiency of the engine. This will further decide the pressure and temperature development in the engine cylinder.
The pressure development in the engine cylinders will decide the manageable force that will act on the piston.

C.I engine.

A Similar analysis can be done for the heterogeneous combustion in a C.I engine.
The **crankshaft rotational speed** will help to compute the time available for each cycle. This in turn will help to compute the time available for the combustion process in each cycle.
In C.I engines, the fuel is injected into the engine cylinder towards the end of the compression process.
There is a delay period between the time of injection of fuel and the time when the flame actually gets developed.
The fuel injection continues with a suitable mass flow rate, injection pressure and stops just before the end of the combustion process.
This time interval should match the available time interval corresponding to crankshaft rotational speed.
We try to get maximum possible combustion efficiency. The will decide the temperature and pressure development inside the engine cylinder.
The pressure developed will decide the manageable force to act on the piston.

a = acceleration and deceleration of piston.

High speed engine – acceleration a is high

So mass m should reduce.

This indicates the need for the design of a **multi-cylinder engine. Each cylinder has a smaller bore and a smaller piston with a reduced mass.**

Detailed Explanation:

(a) Reciprocating mass is reduced by **increasing the number of cylinders**.
(b) By **reducing the number of cylinders** the cylinder **size is increased** the mass of the piston, rings, piston pin, and connecting rod increase as well.
(c) The **mass m of the piston assembly must be continually accelerated and decelerated** since twice every engine revolution their velocities alternate between zero and maximum speed.

(d) **At any instant of time**, the force F transmitted through a connecting rod, and seen by the rod and main bearings, crankshaft, cylinder block, and main bearing caps, is the product of the mass m of the reciprocating components and the instantaneous rate of acceleration a or deceleration.
Or
F = m*a

(e) **Higher engine speed** requirements result in **greater acceleration** rates, and in order **to keep the reciprocating force manageable**, the **reciprocating mass must be reduced**.

(f) It follows directly that **increasing the number of cylinders** is attractive for **high speed engines**, as it **allows the mass to be distributed**, **reducing the force transmitted at each cylinder**.

3. Surface to Volume Ratio:
Or
Surface area to volume ratio.

Surface to volume ratio refers to the **instantaneous** ratio of **combustion chamber** surface area to combustion chamber volume.
This ratio changes instantaneously from crank angle to crank angle as piston moves between TC and BC.

[Note: calculations based on engine geometry at each value of crank angle and also with changing values of B/L ratio will clarify it further]

It is of great importance near TC, when energy is rapidly released during combustion and heat transfer to the combustion chamber walls is to be minimized.

The surface to volume ratio changes by changing the following:

1. Number of cylinders
2. Bore to Stroke ratio.

1. Number of Cylinders:

Increasing the number of cylinders - Increases the surface area to volume ratio.
Reducing the number of cylinders - Reduces the surface area to volume ratio.

2. Bore to Stroke Ratio

The surface to volume ratio is nearly independent of the bore to stroke ratio when piston is at BC.

The surface to volume ratio strongly depends on the bore to stroke ratio when the piston is at TC or near TC.

For the **same cylinder displacement**, a larger bore and shorter stroke engine has a higher surface area to volume ratio and thus greater heat rejection to the cooling system.

Table – Surface to Volume ratio as a function of B/L ratio

Cylinder displacement	B/L	B	L	Combustion Chamber Surface Area	Combustion Chamber Volume	Surface to Volume Ratio	Heat Transfer to coolant
800 cc	0.6 – lower					lower	Low heat transfer
800 cc	0.8						
800 cc	1.0						
800 cc	1.2 - higher					higher	High heat transfer

Conclusions:

1. The heat transfer to the coolant should to be reduced to improve thermal efficiency of the engine.
2. The heat transfer to the coolant is to be optimized as per the requirement of the engine design such as engine lubrication and for achieving a normal and controlled combustion.
3. Corresponding to above two requirements, B/L ratio is also important for consideration during possible division of the engine displacement volume for a multi-cylinder engine.

(4) Pumping Losses.

The pumping losses include the energy needed to bring the air or charge into the engine cylinder and to remove the exhaust gases out of the engine cylinder.

In general:

1. Pumping losses increase as the length of intake and exhaust ducts or pipes increase.
2. Pumping losses increase as the diameter of the intake and exhaust ducts and pipes decrease.

The effect of number of cylinders on the pumping losses of the engine is as follows:

1. **As the number of cylinders increase, additional duct length is often required which will increase the pumping losses of the engine.**
2. The pumping losses can be **reduced by tuning** the intake and exhaust gas manifolds.
   Tuning refers to the selection of duct lengths that result in dynamic pressure pulses aiding the filling and emptying processes at chosen engine speeds. Pressure waves travel in the ducts or pipes of engine manifolds. The discontinuities include the sudden expansion or contraction in the cross sectional area of the ducts or pipes. The frequencies of the pressure waves remains the same. The superposition of the forward moving wave and the reflected wave is solved by applying the D Alembert's principle. The objective function in the design of ducts for the engine manifold is to minimize the magnitude of the reflected waves and to maximize the magnitude of the resultant forward moving wave.
3. Further as the **number of cylinders is increased** the corresponding bore of each cylinder will get reduced.
   This **reduces the permissible diameter** of the ports, valves and ducts needed for gas exchange process from each cylinder of the internal combustion engine
   Therefore as the number of cylinders is increased the pumping losses will also increase.

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Text Book:
Vehicular Engine Design
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