CHAPTER THREE

Induction and Exhaust Processes

3-1 General:

In reciprocating internal combustion engines, the induction and exhaust processes are non-steady flow processes (pulsation flow). For cycle analysis, the flow could be assumed steady. This assumption is reasonable especially for multi-cylinder engines with some form of silencing in induction and exhaust passages.

The inlet and exhaust manifold designs are often determined by consideration of ***cost, easy of manufacturing, space, easy of assembly, low pressure drop and optimum flow***.

3-2 Intake System:

The intake system consists of an air filter, a carburetor and throttle valve or fuel injectors and throttle or throttle with individual fuel injectors in each intake port, and intake manifold. The intake manifold is designed to deliver air or air and fuel to the engine through pipes to each cylinder called runners. The inside diameter of the runners must be large enough so that a high flow resistance and the resulting low volumetric efficiency do not occur. On the other hand, the diameter must be small enough to assure high air velocity and turbulence which enhances its capability of carrying fuel droplets and increases evaporation and air-fuel mixing. The manifold should have:

1) Similar passage ways to all cylinders (same length, diameter and symmetry).
2) Turbulence inducers (high velocities are one means).
3) Hot spots to reduce large liquid droplets.
4) Smooth inner wall to reduce the thickness of liquid film and to minimize flow resistance.

3-3 Valve Types:

3-3-1 Mushroom-Shaped Poppet Valve:

- ***Advantages***: cheep, good seating, easy lubrication, good heat transfer to cylinder head and good flow properties (i.e.; it give larger values of valve flow area to piston area than most other types and it has excellent flow coefficient if properly designed.
- ***Flow Calculation***: the vale lift (ℓ) depending on the engine size, usually about [5 to 10] (mm) for automobile engines.

Generally:

$$\ell_{max} \leq d_v/4$$

Where: ℓ_{max} = Valve lift when valve is fully open.

$d_v/4$ = Diameter of valve

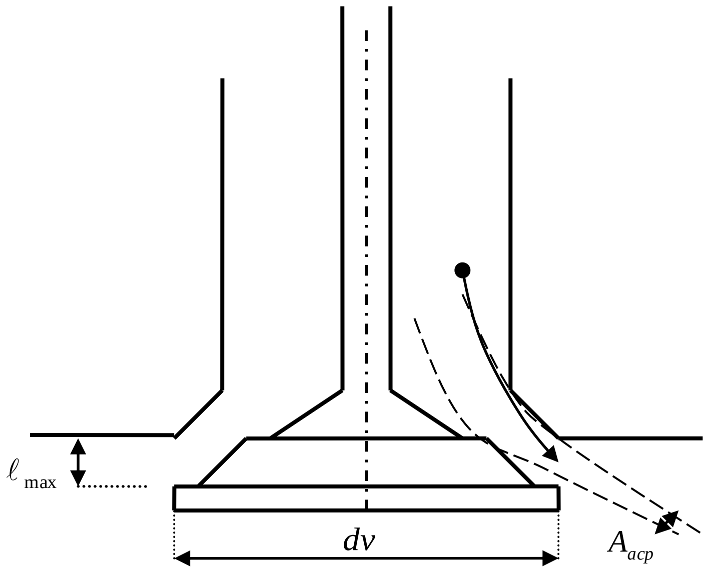


Figure (3-1): Mushroom's valve calculation.

$$C_D = A_{act}/A_{pass} \qquad \ldots (3\text{-}1)$$

Where:

C_D = Discharge coefficient.

A_{act} = Actual flow area (effective area).

A_{pass} = Passage area of flow (curtain area) = $\pi.d_v.\ell_{max}$

$$A_i = 1.3B^2\left[\frac{(\overline{P_s})_{\max}}{C_i}\right] = \frac{\pi . d_v^{\,2}}{4} \qquad \ldots (3\text{-}2)$$

Where:

A_i = Minimum intake valve area for one cylinder.

C_i = Speed of sound at inlet conditions= $\sqrt{\gamma . R . T_i}$, where: (T_i =inlet air temperature).

<u>Note:</u> The angle of valve surface at the interface with the valve seat is generally designed to give minimum flow restriction. As air flow around corners, the stream line separate from the surface and the actual area of flow is less than the flow passage area (A_{act} is less than the A_{pass}). Figure (3-2) below illustrate this case.

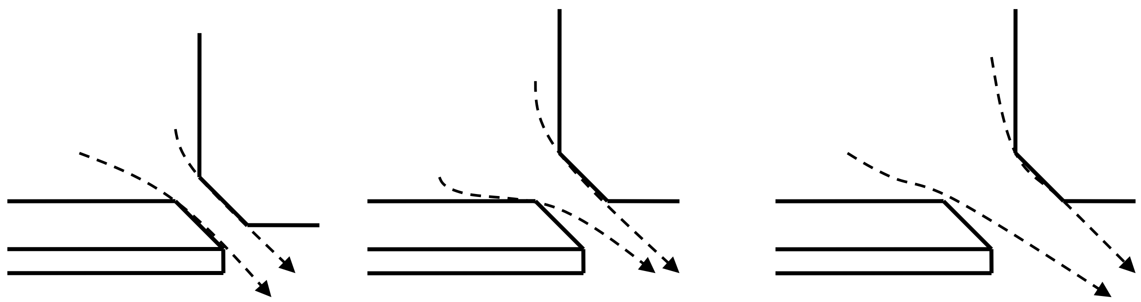


Figure (3-2): The angle of valve surface at the interface with the valve seat.

$$A_{ex} = 1.3B^2\left[\frac{(\overline{P_s})_{\max}}{C_{ex}}\right] \qquad \ldots (3\text{-}3)$$

Where:

A_{ex} = Exhaust valve area

C_{ex} = Sonic speed at exhaust temperature

$$\phi = \frac{A_{ex}}{A_i} = \frac{C_i}{C_{ex}} = \frac{\sqrt{\gamma . R . T_i}}{\sqrt{\gamma . R . T_{ex}}} = \sqrt{\frac{T_i}{T_{ex}}}$$

Where:

$\phi =$ Valve area ratio

$T_i =$ Flow temperature at inlet

$T_{ex} =$ Flow temperature at exhaust

In actual engines, (ϕ) usually has a value of about (0.8-0.9). To find the valves diameter:

$$\frac{A}{x} = \frac{\pi . d_v{}^2}{4}$$

Where:

$x =$ Number of intake valves or number of exhaust valves per cylinder.

Mach index (Mach number):

$$M = \frac{\text{Velocity of flow}}{\text{Inlet sonic velocity}} \quad \text{… (3-4)}$$

Assume the flow is incompressible, then:

Volume flow rate through the piston = Volume flow rate through the valve

$$\overline{P_s} * A_s = V * A_i$$
$$or:$$
$$V = \frac{\overline{P_s} * A_s}{A_i} \quad \text{… (3-5)}$$

Where:

A_s = Piston area = $\frac{\pi . B^2}{4}$

V = Velocity of the flow passing the valve.

Substitute equation (3-5) into (3-4):

$$M = \frac{\overline{P_s} * A_s}{A_i} * \frac{1}{C_i} \quad \text{… (3-6)}$$

❖ ***Valve Operation System***:

1) Over head valve (ohv): The valves are operating from the camshaft via cam followers, push road and rockers. Figure (3-3) illustrates the over-head valve construction.

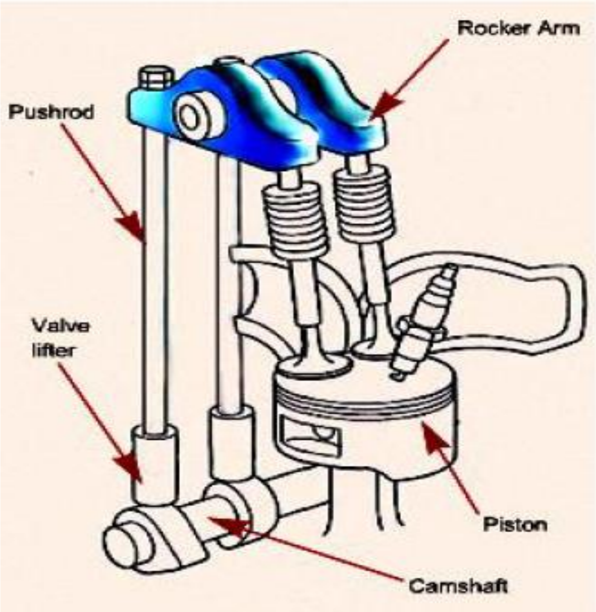


Figure (3-2): over-head valve.

2) Over head Camshaft (ohc): The camshaft can be mounted directly over the valve stems or it can be offset when the camshaft is offset the valves are operated by rockers.

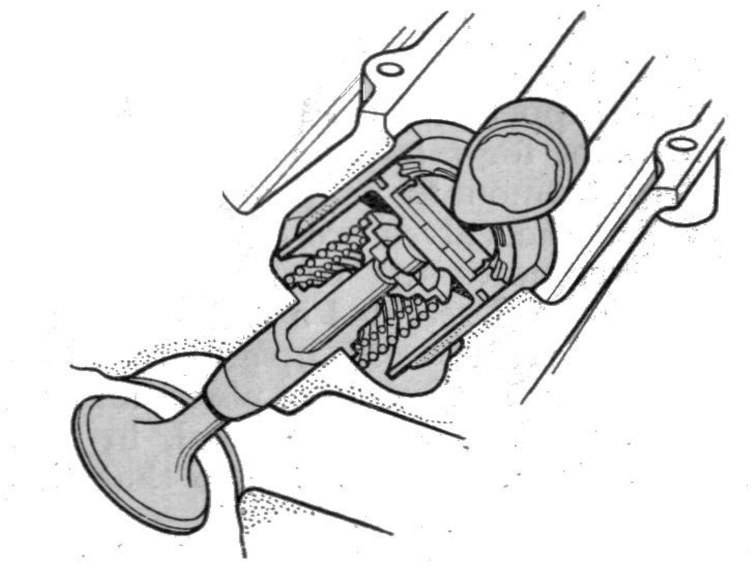


Figure (3-4): Over-head camshaft.

Figure (3-5): Offset valve.

3-3-2 Sleeve Valve:

They are consisted of a single sleeve or pair of sleeves between piston and the cylinder with inlet and exhaust ports. Figure (3-6) below shows the sleeve valve in details.

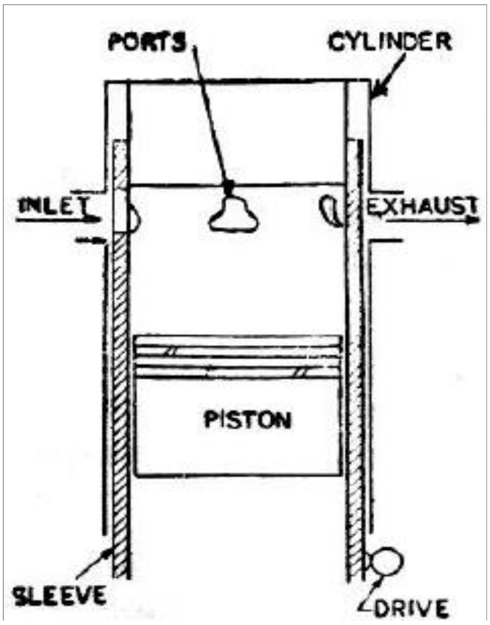


Figure (3-6): Sleeve valve.

❖ ***Advantages of Sleeve Valves***:

1) Elimination the hot spot associated with a poppet valve (this is very important when only low octane fuel are available).
2) Compact engine when compared with engine using poppet valve.
3) Piston lubrication is improved since there was always relative motion between the piston strokes.

❖ ***Disadvantages of Sleeve Valves***:

1) Cost
2) Difficulty of manufacturing
3) Lubrication and friction problems between cylinder and sleeve
4) Heat transfer problem from piston through the sleeve and oil film to the cylinder.

Note: Motion of sleeve valve is half engine speed and under went vertical and rotary oscillation.

3-3-2 Rotary, Disc and Slide Valves: are still sometimes used, but are subject to heat transfer, lubrication and clearance problems.

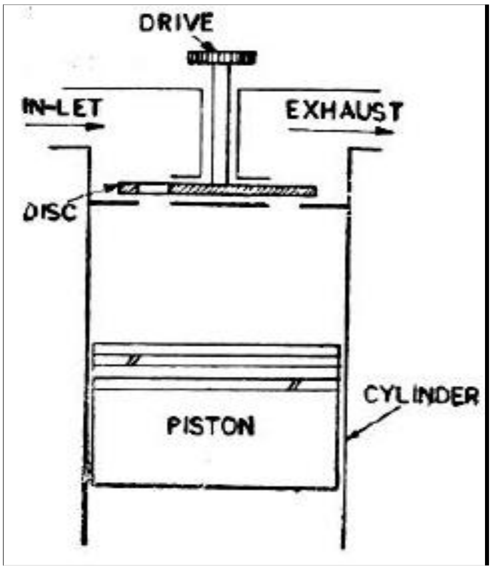


Figure (3-7): Rotary Valve.

- ***The Advantages of Four Valves per Cylinder***:
    1) Large valves throat area for gas flow.
    2) Good heat transfer due to larger seat area.
    3) Smaller valve forces occur since a lighter valve with lighter spring can be used. This will also reduce the hammering effect on the valve seat.

3-4 Exhaust System:

After leaving the cylinders by passing out of the exhaust valves, exhaust gases pass through the exhaust manifold, a piping system that directs the flow into one or more exhaust pipes.

The pressure pulses in the exhaust system are much greater than those in the inlet system, since in a naturally aspirated engine the pressures in the inlet have to be less than about (1 bar).

In designing the exhaust system for a multi-cylinder engine, advantage should be taken of the pulsed nature of the flow. The system should avoid sending pulses from the separate cylinders into the same pipe at the same time, since this will lead to increase the flow losses. However, it is sensible to have two or three (2 or 3) cylinders that are out of phase ultimately feeding into the same pipe. When there is a junction, [see figure (3-8) below], a compression wave will also reflect an expansion wave back. If the expansion wave returns to the exhaust valve at the end of the exhaust valve opening, then it helps to scave the combustion products if the inlet valve is also open then it will help to draw in the next charge. Obviously the cancellation of compression and expansion wave must be avoided.

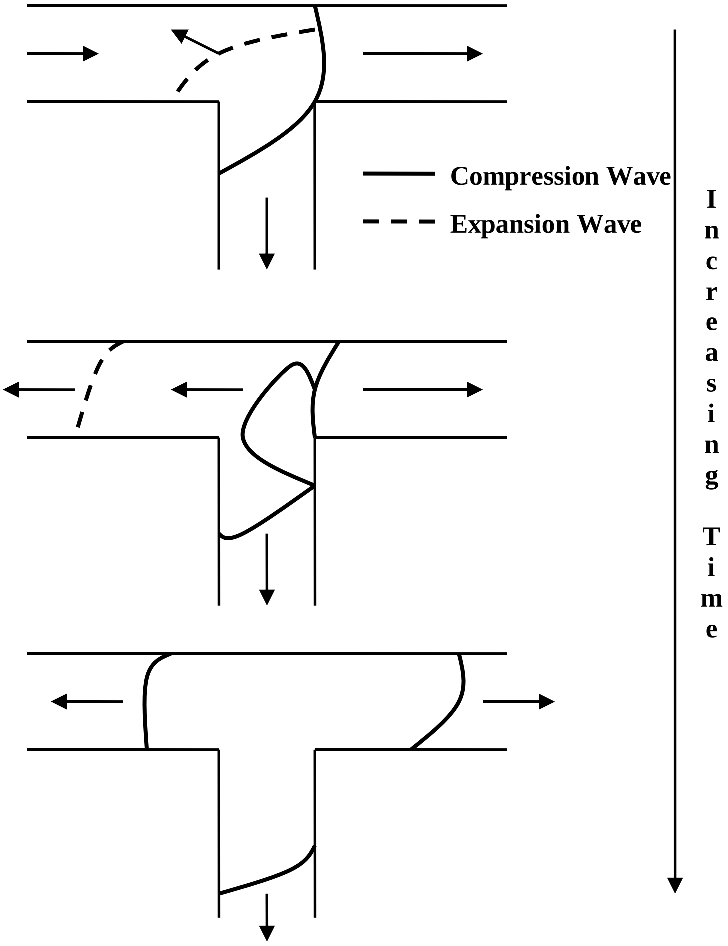
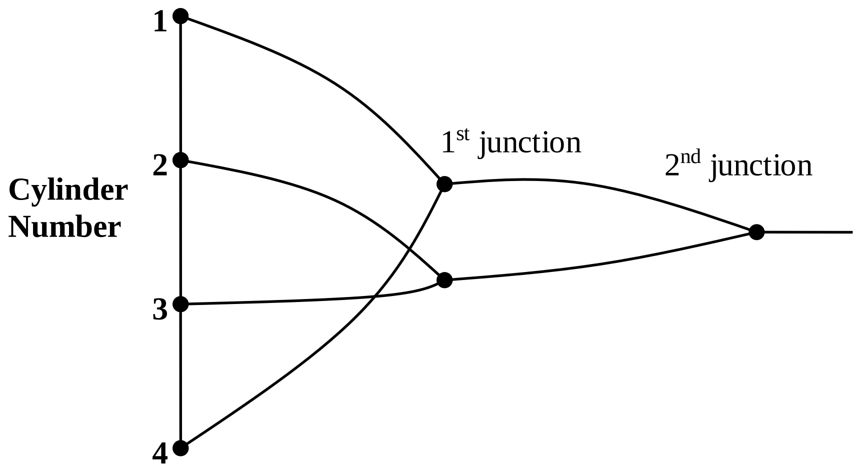


Figure (3-8): Compression and Expansion Waves.

<u>Example:</u> Arrange the exhaust system for a 4-cylinder, 4-strokes engine having firing order [1-3-4-2].



Explanation:

Consider the engine operating with the exhaust valve just opening on (cylinder-1). A compression wave will travel to the first junction; since the exhaust valve on (cylinder-4) is closed, an expansion wave will be reflected back to the open exhaust valve. The same process occurs (180°) later in the junction connecting cylinders (2 and 3). At the second junction, the flow is significantly steadier and ready for silencing.

3-5 Carburetor Arrangement for Multi-Cylinder:

Inlet manifolds are usually designed for easy of production and assembly, even on turbocharged engines when a single carburetor per cylinder is used. The flow pulsation will cause a rich mixture at full throttle as the carburetor will feed fuel for flow in either direction. In engines with a carburetor supplying more than one cylinder, the flow at the carburetor will be steadier because the interaction between compression and expansion waves.

3-5-1 For Single Carburetor:

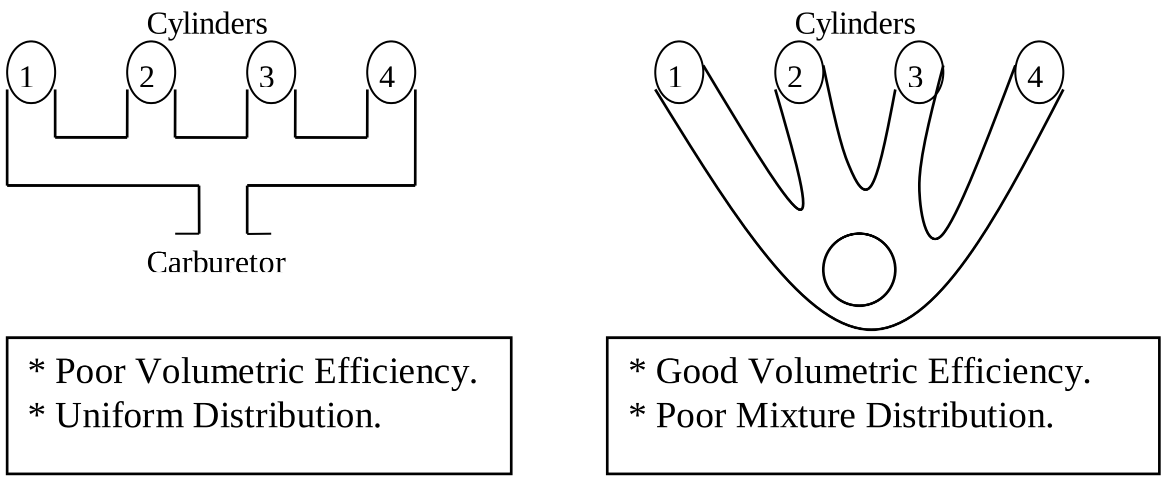


Figure (3-9): Single Carburetor.

3-5-2 For Twin Carburetor:

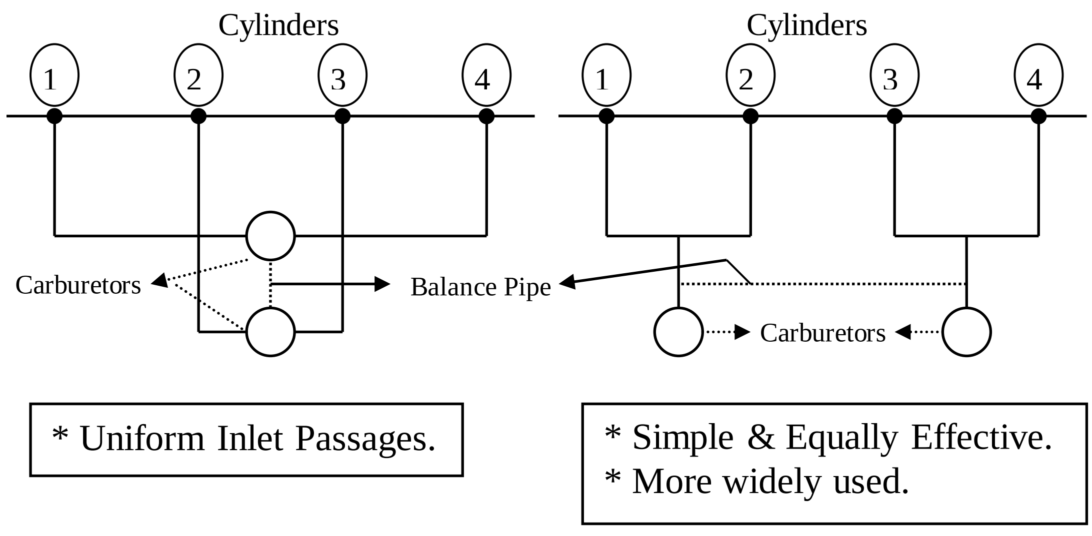


Figure (3-10): Twin Carburetor.

3-6 Valve Timing Diagram:

3-6-1 P-V Diagram:

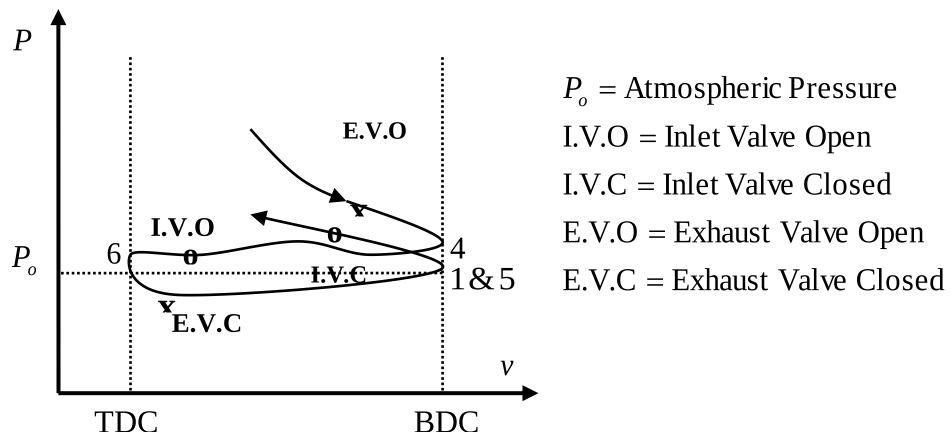


Figure (3-11): P-V Diagram.

3-6-2 Open Diagram for 4-Strokes Engine:

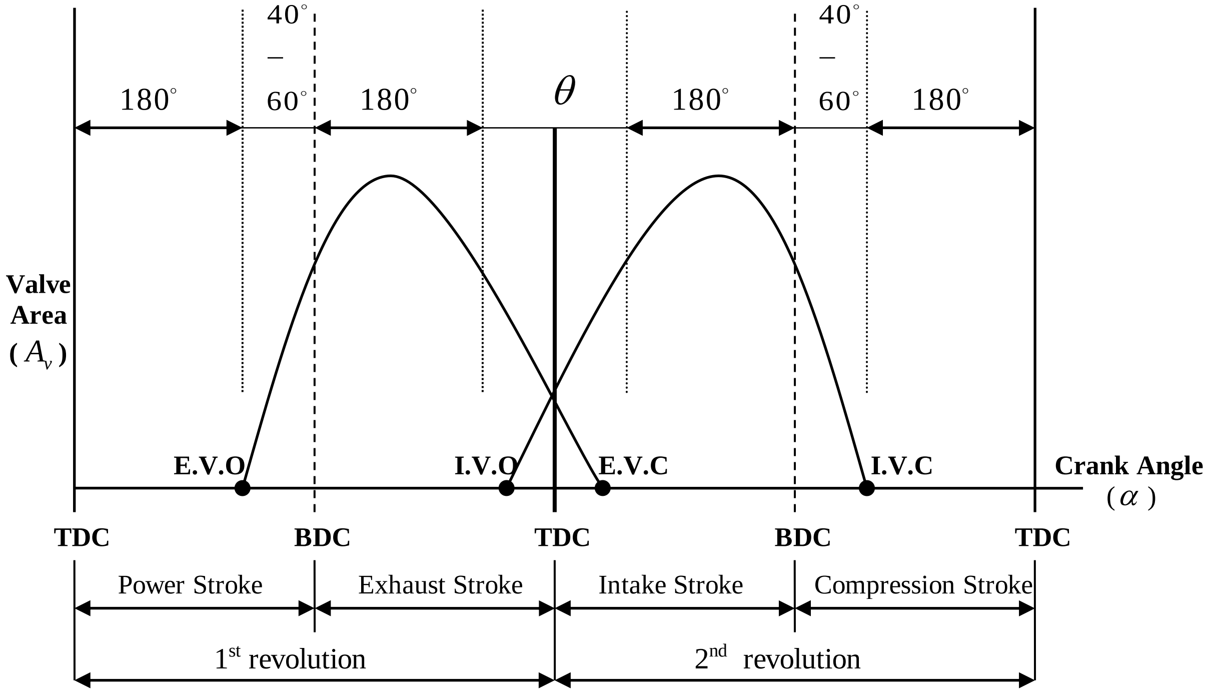


Figure (3-12): Open Diagram for 4-Strokes Engine.

θ = angle of valve over-lap.

3-6-3 Polar Diagram for 4-Strokes Engine:

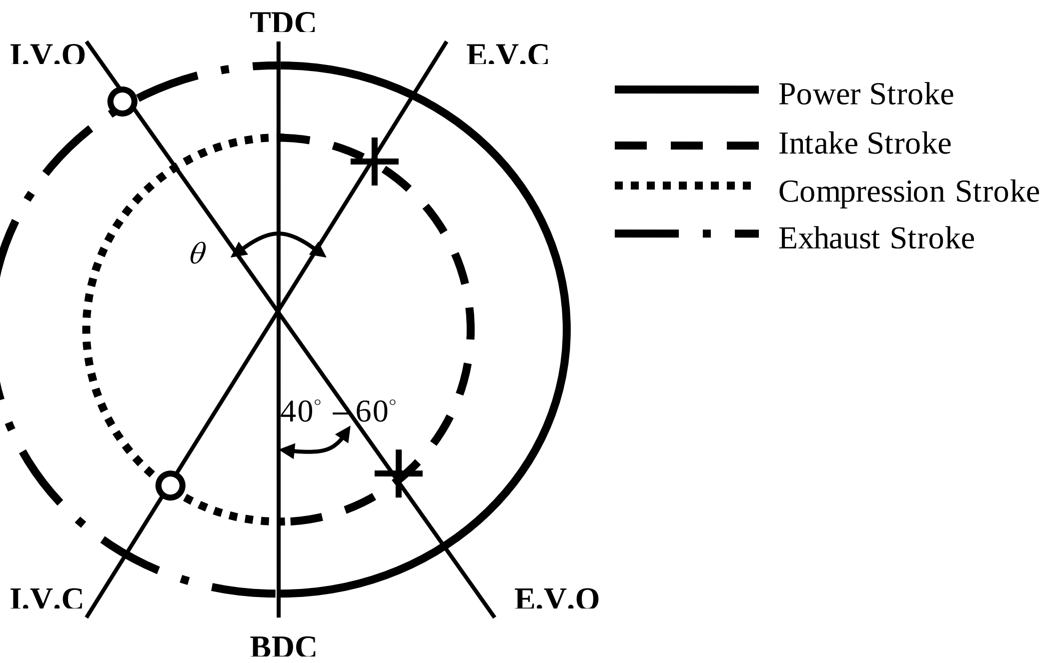


Figure (3-13): Polar Diagram for 4-Strokes Engine.

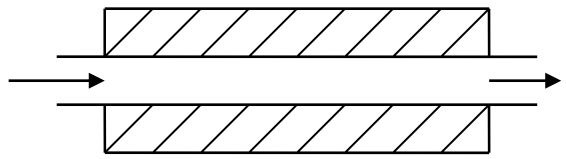
3-7 Silencing:

The most effect approach to silencing is the reduction of the peaks, especially those in the most sensitive frequency rang of the ear.

The inlet noise is attenuated by the air filter and its housing, the air filter is also acts as a flame trap if the engine back-fire.

Exhaust silencers work either by absorption or by modifying the pressure wave in such away as to lead to cancellation and reduction in sound. Absorption silencers work by dissipating the sound energy in porous medium.

3-7-1 Absorptive Silencer:



3-7-2 Modifying Pressure Waves:

a) Expansion Box

b) Side Resonator

c) Constriction

d) Interface Filter