Internal Combustion Engines

Intake & Exhaust Valves

Ujjwal K Saha, Ph.D.
Department of Mechanical Engineering
Indian Institute of Technology Guwahati
The poppet valve is so called because it pops up and down. Also, known as mushroom valve as the valve head looks like a mushroom.
Intake Valves

Intake valves of most engines are poppet valves that are spring-loaded closed and pushed open at the proper time by the camshaft. They have the advantage of being cheap, good seating, easy lubrication and good heat transfer to the cylinder head.

Components include:

A. valve seat,
B. head,
C. stem,
D. guide,
E. spring,
F. camshaft, and
G. manifold.
Poppet Valve Actuation with Overhead Camshaft

- Camshaft
- Spring
- Guide
- Stem
- Air manifold
- Valve head
- Valve seat
- Piston
- Spark plug
Valve Mechanisms

- Lobe
- Camshaft
- Valve lifter
- Push rod
- Rocker
- Piston
- Cam
- Crankshaft

Timing marks
1. Cam
2. Tappet
3. Valve
4. Spring
5. Spring Retainer
6. Valve guide

1. Tappet Clearance
2. Tappet
3. Valve

1. Cam Projection
2. Tappet
3. Push rod
4. Rocker arm
5. Valve
Valve “Float”

The valve spring normally keeps the top of the valve stem in contact with the cam lobe.

At very high engine speeds, and thus high camshaft speeds, it is difficult to maintain contact between the cam lobe and the top of the valve stem as a result the valves stay open longer than desired.
Valve Opening and Closing

In thermo cycles, it is assumed the valves open and close instantaneously. In reality, a cam is used to progressively open and close the valves, the lobes are contoured so that the valve land gently on the seat.
Various parts of valves with typical exhaust temperatures
Some valves have a hollow stem to reduce the valve weight. Lighter valves reduce the effect of inertia.

To help cool exhaust valves, hollow stems are partly filled with metal sodium. Sodium melts at 97.8°C. When the engine runs, sodium is a liquid, and the valve movement throws the sodium up and down in the stem. This circulation takes heat from the valve head and carries it up to the cooler stem. A sodium filled exhaust valve runs about 93.3°C cooler than a non-filled valve.
• **Intake valve:** a chromium-nickel alloy.

• **Exhaust valve:** a silicon-chrome alloy since it operates at higher temperatures (about 1200°F).
When flow separates from the surface at the corners, actual flow area is less than the geometric passage area.
Flow separates from both seats

Flow reattaches to both outer seat edges

Outer seat edges

Inner seat edges

Flow separates and remains free from both outer edges

(a) Inlet valve-low lift
(jet fills gap)

Flow separates and then reattaches itself to outer seat edge

Flow remains separate from outer seat edge

(b) Inlet valve-intermediate-lift

(c) Inlet valve-high lift
(free jet formed)

Flow separates and remains free from both outer edges

Flow separates and reattaches itself to both seat inner edges

(d) Exhaust valve-low lift

(e) Exhaust valve-high lift
$l = \text{valve lift when the valve is fully open}$

$d_v = \text{valve diameter}$

Generally,

$$l_{\text{max}} \leq \frac{d_v}{4}$$

Discharge Coefficient,

$$C_{D_v} = \frac{A_{\text{act}}}{A_{\text{pass}}}$$

The passage area of flow,

$$A_{\text{pass}} = \pi d_v l$$
Various empirical relations are available for sizing the intake valves. The following equation gives the minimum valve intake area necessary for a modern engine:

\[
A_i = CB^2 \frac{\bar{U}_p}{c_i} = \frac{\pi}{4} d_v^2
\]

where:
- \(C\) = constant having a value of about 1.3
- \(B\) = bore
- \(\bar{U}_p\) = average piston speed
- \(c_i\) = speed of sound at inlet conditions
- \(d_v\) = diameter of valve
- \(A_i\) = total inlet valve area for one cylinder (whether it has one, two or three valves)
- For a given combustion chamber size, two or three smaller valves will give more flow area than one larger valve.

- These multi-valve engines involve a greater complexity of design with more camshafts and mechanical linkages.

- Use of multi-valves makes the valves smaller and lighter, and can be used in conjunction with lighter springs with reduced forces in the linkages.
(a) Used in early overhead valve engines (1950s-1980s), and a few modern engines.  
(b) Used in present day automobile engines.  
(c) Used in some modern high-performance engines.
Advanced Design

- Some engines are so designed that one intake valve operates at low speed; and as the speed is increased, the 2\textsuperscript{nd} (and sometimes the 3\textsuperscript{rd}) valve actuates, giving additional flow area.

- This allows the increased control of flow of air within the cylinder at various speeds resulting in more efficient combustion.

- Usually, the low speed valve closes at a relatively early point aBDC, and the high speed valve closes at a later position to avoid lowering the volumetric efficiency.
Valve Timing Diagrams

(a) Small valve overlap
(b) Large valve overlap
Exhaust Valves

- Exhaust valves are usually smaller than the intake valves, even though the mass flow is constant.

Pressure differential across the intake valve < 1 atmosphere

Pressure differential across the exhaust valve (during blow-down) > 3 to 4 atmosphere

For choked flow,

\[(\text{sonic flow})_{\text{exhaust valve}} > (\text{sonic flow})_{\text{intake valve}}\]

This is due to high gas temperature.
Exhaust Valves

For multi-cylinder engines, $A_i$ and $A_{exh}$ are total areas in one cylinder.

\[ A_i = CB^2 \frac{\bar{U}}{c_i \bar{U}} \]
\[ A_{exh} = CB^2 \frac{p}{c_{exh}} \]

\[ \alpha = \frac{A_{exh}}{A_i} = \frac{c_i}{c_{exh}} \]

\[ \alpha = \sqrt{\frac{kRT_i}{kRT_{exh}}} = \sqrt{\frac{T_i}{T_{exh}}} \]

\[ = 0.8 \text{ to } 0.9 \]
Valve Sizing

In order to avoid choked flow the intake valves are sized based on:

$$A_v \geq 1.3 b^2 \frac{\bar{U}_p}{c_i}$$

where $A_v$ is the average valve area, $b$ is the cylinder bore, $\bar{U}_p$ is average piston velocity, $c_i$ speed of sound of gas in intake port.

Exhaust valves can be smaller since the speed of sound of the exhaust gas expelled is significantly larger.

Since there is only so much room available for valves it is common to have multiple intake and exhaust valves per cylinder. This increases valve area to piston area ratio permitting higher engine speeds.
Valve Sizing

Heads are often wedge-shaped or domed, this permits $A_v/A_p$ up to 0.5.

Double overhead cams per cylinder bank are used to accommodate multiple valves, one cam for each pair of intake and exhaust valves.
Valve Overlap

In real engines in order to ensure that the valve is fully open during a stroke, for high volumetric efficiency, the valves are open for longer than 180°.

The exhaust valve opens before BC and closes after TC and the intake valve opens before TC and closes after BC.

At TC there is a period of time called valve overlap where both the intake and exhaust valves are open.
Valve overlap

When the intake valve opens bTC the cylinder pressure is at roughly $P_e$

**Part throttle** ($P_i < P_e$): residual gas flows into the intake port. During intake stroke the residual gas is first returned to the cylinder then fresh gas is introduced. Residual gas reduces part load performance.

**WOT** ($P_i = P_e$): some fresh gas can flow out the exhaust valve reducing fuel efficiency and increasing emissions.

**Supercharged** ($P_i > P_e$): fresh gas can flow out the exhaust valve.
Engine Operating Conditions

Conventional engines operate at low rpms, with idle and part load fuel economy being most important.

High performance engines operate at high rpms, with WOT torque (i.e., volumetric efficiency) being most important.

<table>
<thead>
<tr>
<th>Engine speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle</td>
</tr>
<tr>
<td>Economy</td>
</tr>
<tr>
<td>Performance</td>
</tr>
<tr>
<td>1000 rpm</td>
</tr>
<tr>
<td>2500 rpm</td>
</tr>
<tr>
<td>4000 rpm</td>
</tr>
</tbody>
</table>

Engine load

"Engine load"
Valve Timing

<table>
<thead>
<tr>
<th></th>
<th>Open</th>
<th>Close</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake</td>
<td>Conventional</td>
<td>5° before tdc</td>
<td>45° after bdc</td>
</tr>
<tr>
<td></td>
<td>High performance</td>
<td>30° before tdc</td>
<td>75° after bdc</td>
</tr>
<tr>
<td>Exhaust</td>
<td>Conventional</td>
<td>45° before bdc</td>
<td>10° after tdc</td>
</tr>
<tr>
<td></td>
<td>High performance</td>
<td>70° before bdc</td>
<td>35° after tdc</td>
</tr>
</tbody>
</table>

Conventional

@1000 rpm intake duration: 230° = 38.4 ms
@2500 rpm      230° = 15.4 ms
@5000 rpm      230° =  7.7 ms,  285° =  9.5 ms
Honda Variable valve Timing and lift Electronic Control (VTEC)

Each pair of valves has three cam lobes, two that operate the valves at low-rpm, and a third that takes over at high rpm (4500 rpm).

During low-rpm operation, the two rocker arms riding the low-rpm lobes push directly on the top of the valves. At high rpm a pin locks the three rocker arms and the valves follow the larger center cam lobe.

First introduced in 1991 Honda NSX model.
Solenoid Activated Valves

Needs a large alternator to supply high current, also gently seating the valve is difficult, needs sophisticated electronics
References

Web Resources

1. http://www.mne.psu.edu/simpson/courses
2. http://me.queensu.ca/courses
7. http://www.me.psu.edu
8. http://www.uic.edu/classes/me/me429/lecture-air-cyc-web%5B1%5D.ppt
11. http://www.tpub.com/content/engine/14081/css
15. http://www.ku.edu/~kunrotc/academics/180/Lesson%20Diesel.ppt
17. http://www.career-center.org/secondary/powerpoint/sgc-parts.ppt
21. http://www.me.udel.edu
22. http://online.physics.uiuc.edu/courses/phys140