

Powertrain Technology

M4X02196

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Part 2.

Induction Manifolds

A Manifold is defined: A system of passages which conduct the charge mixture to the port and valves.

A Manifold must consists of the following:

- Plenum- Collects and Diffuses Air.
- Throttle Bodies
- Feeding Branches.

Design Criteria:

- Low air flow resistance.
- Good distribution of charge between the cylinders.
- Sufficient heating to insure fuel vaporisation with carburetted or fuel injected throttle bodies.
- Feeding branch lengths that take advantage of ram and tuning effects.

Generally: (Four cylinders) Four branches link the plenum, beneath the carb' or throttle bodies, to the inlet ports, all of which are of similar length and geometry. Manifolds can be heated by engine coolant or by a heated grid beneath the carb'/throttle bodies.

Why?.....
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Some also use the heat from the exhaust to heat the plenum.

With port fuel injection there is no need for heated manifold because the cylinder head is hot and the fuel is injected into the hot port.

Induction Tuning

- Takes advantage of the natural 'supercharging' effect of the induction system. Newtons 1st Law is the foundation of most induction tuning.

Inertia/Ram effect

This is where the intake uses the dynamic air pressure created by the motion of a vehicle to increase the static air pressure inside of the intake manifold on an engine, thus allowing a greater mass flow rate through the engine. This works by reducing the intake velocity by increasing the cross sectional area of the intake ducting. When gas velocity goes down the dynamic pressure is reduced while the static pressure is increased (in accordance with Bernoulli's Law). The increased static pressure in the plenum chamber has a positive effect on engine power, both because of the pressure itself and the increased air density this higher pressure gives. Ram-air systems are most often used on high performance vehicles, motorcycles and race cars. However ram induction is highly affected by the ambient temperature and pressure which means positioning of the intake is critical. For example in some vehicles the intake is placed behind the radiator, where not only is the air hot, but the pressure is below ambient pressure. This will have a detrimental effect on how effective the system is.

Expansion chamber resonators or Helmholtz resonator:

Relies on a cylinder of air connected to atmosphere which will resonate at its natural frequency increasing the pressure in the cylinder momentarily. In an engine, the air-fuel mixture is sucked inside the cylinder while the piston is moving down to BDC. Throughout induction the charge gains more momentum (mv), and the speed of the charge air increases gradually. As soon as the piston reaches BDC the inlet valve closes, but the air in the intake manifold still has a substantial amount of velocity (or dynamic pressure). This flowing charge hits the closed valve, and the pressure of the charge air at the vicinity of the valve increases. The pressure wave bounces back and starts moving in the opposite direction away from the valve. When a resonator is attached with the inlet manifold, it will act like a 'spring' to the just created pressure wave. The frequency of the resonator and the speed of the engine (which determines

the interval between opening and closing of the inlet valve) are properly tuned, the pressure wave will hit the inlet valve again at the time when the inlet valve is open. This phenomenon will cause the rush of charge into the cylinder causing an increase in the volumetric efficiency. One example of which is a Helmholtz resonator.

Resonant frequency is given by:

$$n = \frac{c}{2\pi} \sqrt{\frac{A}{IV}}$$

n = resonant frequency (Hz)

c = speed of sound of the fluid (343.2 m/s)

A = area of the pipe (m²)

L = length of the inlet tract (m)

V = resonator volume (m³)

The Helmholtz resonator approach is also applied to air boxes, of race engines.

Example

An air box has a volume of 1.75 litres, and an inlet port has a diameter of 45mm, given that the airbox has a resonator frequency of 130Hz calculate the length of the inlet tract. (1l=0.001m³)

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Wave/Pulse tuning

- This wave effect is initiated by the opening of the inlet valve. The sudden depression causes a negative pressure wave to travel back up the inlet port where it is reflected at the open end and travels back towards the valve as a positive pressure wave as the inlet valve closes.
- This charge becomes compressed behind the valve.
- The compressed charge still has momentum (1st Law) and so will rotate and travel back up the manifold branch in the form of a pressure wave.
- The wave bounces back and forth in the branch and eventually will be drawn to the cylinder when next the valve opens, helped by different vacuums in the induction manifold.
- To fully utilise the pressure wave, it must be timed correctly, hence it is important to be able to calculate the time taken for a pressure wave to travel 2x the length of the inlet port.
- Time take = distance travelled/local speed of sound.

Ram or Pulse Tuning for Performance

We have discussed the way charge backs up behind a shut valve, becomes compressed forming a pressure wave that travels in the form of a longitudinal wave, but we can now calculate how to use this wave to the advantage of engine tuning.

Pulse-ram induction is a method by which improved cylinder charging can be accomplished based solely on the geometry of the intake system. Commonly known as induction tuning, it uses pressure-pulse phenomena created by the piston motion to 'ram' a high-density charge of intake gas into the cylinder, thereby improving volumetric efficiency. Since it requires no engine-driven mechanisms, it is commonly considered a 'free' boost. However, as explained later, proper tuning often requires large manifold dimensions. In many modern vehicles, where engine optimization is often subordinated to styling and packaging considerations, designers are unable to employ this principle to its full potential.

Some methods consider the pulse as a single event from generation until valve closing. Others involve modelling the effect as a standing wave using organ-pipe theory.

The pulse-ram process is best visualized by considering a simple intake pipe on a single cylinder. The intake valve is opened slightly before the piston reaches top dead centre (TDC), or 0° crankshaft angle on the exhaust stroke. When the piston begins its downward travel on the intake stroke, a depression is created in the cylinder and the depression's amplitude follows the sinusoidal profile of the piston speed. When it reaches the atmosphere at the open end of the pipe, it is reflected as a compression wave. Of course, when the first reflected pulse reaches the intake port, some of it will be re-reflected towards the open end. However, each subsequent reflection will suffer an exponential reduction in amplitude due to attenuation. Therefore, it is desirable to tune the intake to capture the first and strongest reflected pulse. If properly timed, this first reflection can assist cylinder filling.

This model of the pulse phenomena is based on the acoustic wave model. Such modelling requires the assumption that the pressure pulse behaves as a sound wave of infinitesimal thickness. Actually, it is a finite amplitude wave of finite thickness. However such an assumption is valid since it is the speed of the wave's centre which is of interest. Air (as an ideal gas) is assumed to be the working fluid, and it can be shown that assuming no variations in local speed of sound will not reduce accuracy.

It should be noted that a manifold tuned for maximum performance at multiple engine speeds would produce a flatter torque curve, and improve performance over a greater range than the simple tuned pipe.

Let's consider the **induction** cycle:

- Say the valve opens at 355° crank rotation i.e. 5° before TDC,

N.B. Engine rotates twice (720°) for one intake opening

- Therefore $720^\circ - 355^\circ = 365^\circ$ of crank rotation that the inlet is closed.
- So let's look at what happens at 3000 rpm

$$3000/60 = 50\text{rev/sec}$$

- $50\text{rev/sec} \times 360^\circ/\text{rev} = 18000^\circ/\text{sec}$
- So $365/18000 = \mathbf{0.02}$ seconds

This is our critical time factor. The valve is closed for 0.020 sec and our pulse wave is modelled on an acoustic wave it must move at the speed of sound 343.17m/s.

Therefore the distance it travels can be calculated quite easily:

$$v=d/t \text{ therefore } d = vt = 343.17 \times 0.02 = 6.92\text{m}$$

So the wave has to travel 6.92m to arrive at the valve when it next opens.

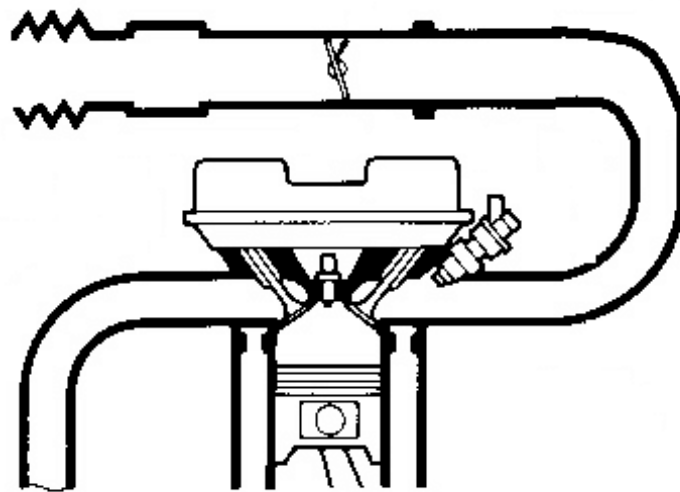


Figure 1: Pulse wave travelling along the inlet tract.

Exercise

Calculate the distance travelled by a pulse wave in:

- A Nascar engine at 8500rpm whose inlet valve opens at 60° before TDC.
- A mild race engine at 6000rpm whose inlet valve opens at 20° before TDC.

[illegible]

SOHC vs DOHC

- At low engine speeds 1 intake valve gives increased charge velocity due to its nozzling effect (Bernoulli's law) hence giving better mixing and cylinder filling.
- The introduction of a second valve decreases the charge velocity losing these good characteristics.
- At high rpm valves are open for less so two valves are better for getting more charge into the cylinder improving volumetric efficiency.
- Two valves give better swirl properties improving mixing and thus combustion which can only be achieved by offsetting a single valve.
- The effectiveness of two valves can be cancelled out by a poorly designed poor flowing exhaust.

Essentially 4 valves gives good high end torque and 2 valves gives low end torque.

Weight: The mass of rotating parts saps the engine power giving a lower torque at lower engine speeds for the DOHC since it has more moving parts to initiate. Once these parts are rotating less power is lost so torque at higher engine speeds is good. For SOHC the low engine speed torque is better as there is less weight of moving parts to move and the valve open easier. Also heavier valve train can result in more valve float for DOHC.

Manufacturing Costs: Double the parts for the DOHC. Also the DOHC cylinder head is slightly larger than that of the SOHC.

Spark: For the SOHC the spark plug is robbed of its optimum position as the camshaft sits over the top so is off-set.

Activity: Discuss where the spark plug is best positioned?

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Also: Some SOHC motors are push rod engines with a cam in the block rather than on top of the cylinder head. The major advantage of this being that the drive for the camshaft has less to travel so timing the engine can be more accurate.

The power band is longer on twincam.

Power Curves



Torque Curves



Given the above information, what would be the ideal camshaft and valve set up?.....

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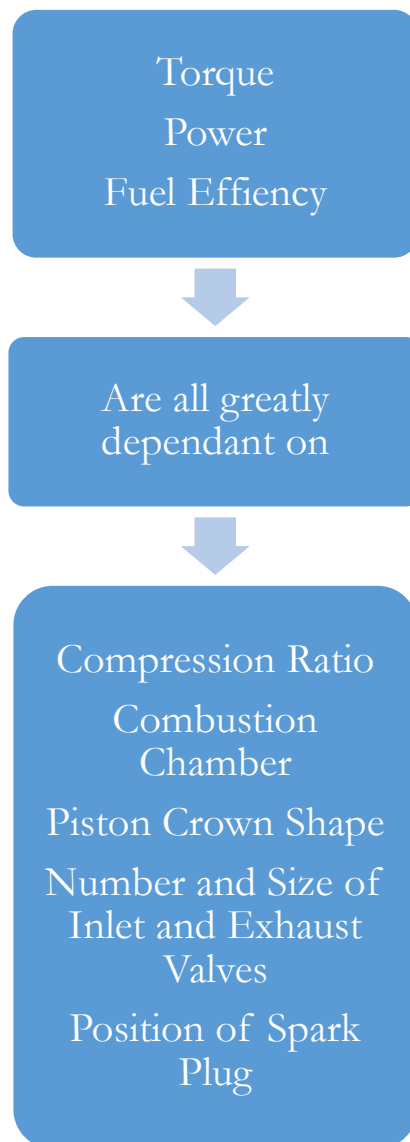
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Combustion Chamber Design



There are two basic objectives of good combustion chamber design:

1. Optimise the charging and exhausting of the cylinder throughout the rev range.
2. Create the ideal conditions for air and fuel to be mixed such that combustion occurs as quickly as possible.

Induction Swirl

Swirl is the rotational flow of charge within the cylinder parallel to its axis. It is produced by off-setting the induction port to one side of the cylinder axis encouraging air to spiral as it comes into contact with the cylinder wall. See figures 2 and 3.

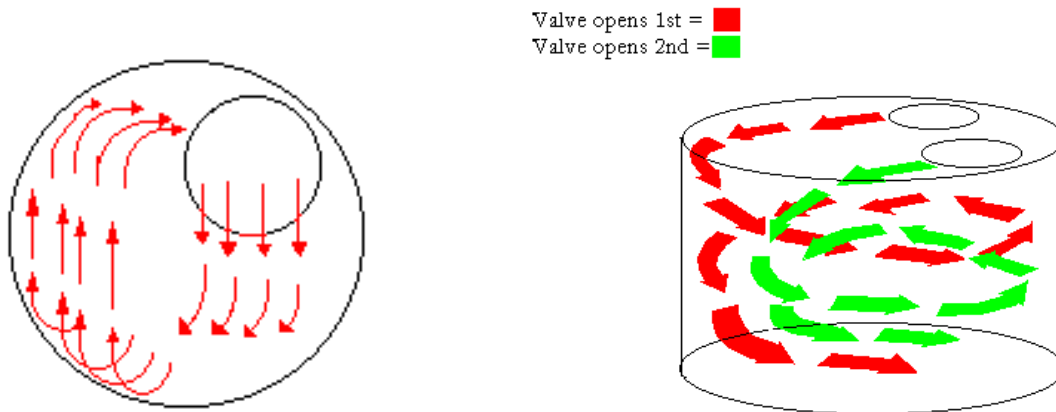


Figure 2: Swirl: Plan View

Figure3: Swirl: Side view

Port types which encourage swirl

Direct straight port: Where air or mixture travels through a straight and parallel port into the cylinder tangential to the cylinder axis where it deflects off the cylinder wall sideways and downwards in a spiral motion enhanced by the motion of the piston.

Figure 4: Straight port: Plan View

Figure 5: Straight port: Side View

Deflector wall port: A curved or tapered port passage provides a semi-circular flow path towards the open valve; this gives the air/charge flow a predetermined downward spiral. This has less emphasis on the cylinder wall and more on the port shape.

Figure 6: Deflector port: Plan view

Figure 7: Deflector port: Side view

Masked Valve Port

This is where the valve head masks the flow of air/mixture into the cylinder forcing it to swirl downwards on entry to the cylinder. This reduces the volumetric efficiency of the cylinder but benefits swirl.

Helical Port

The air/ mixture flow is already spiralling before it enters the chamber. Downward motion of the cylinder from TDC encourages this further. These ports are less dependent on their position in relation to the cylinder wall.

Figure 8: Helical port: Plan view

Chamber Wall Deflected Induction Swirl

Mixture entering the cylinder from a steep port can be forced to move downwards and rotate if the valve is positioned close to the chamber wall.

Figure 9: Chamber wall induced swirl

Other Mechanisms of Improving Burn Rate

Squish: This is the compression of trapped charge formed between the piston crown and the cylinder head face. As the piston reached TDC the mixture is squashed at a relatively high velocity. This pressurised mixture is then suddenly released into the large space of the combustion chamber greatly improving turbulence, mixing and hence combustion. See figure 10

Figure 10: Squish: Side view

Quench: A very thin layer known as a 'lamina' of charge is trapped in the squish area and condenses against the cooler parts of the combustion chamber assisting in maintaining a steady and not violent burn rate. This reduces the tendency for any high speed detonation or pre-ignition. It should be noted that too much quench results in not enough of the charge being combusted giving a lower power output, higher fuel consumption and high quantities of hydrocarbons in the exhaust.

Tumble: Tumble has the same effect of mixing the charge and aiding combustion but is particularly effective at slower air speeds, a good property for engines with shorter induction systems and slower speed mixture flow. A technique for speeding up the airflow into the port is to narrow the gauge of the port which has a similar effect to that of a nozzle increasing the speed of the flow on exit.

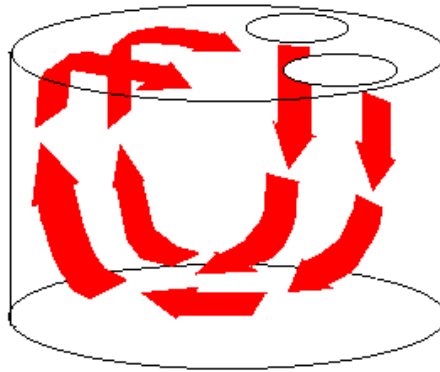


Figure 11: Tumble or Barrel Swirl Mechanism

Turbulence: Consists of dispersed vortices' within the body of air/charge flow that speed up the rate of heat transfer and fuel mixing. See Figure 12.

Figure 12: Turbulence

Incidentally we can apply the equations of motion to Swirl!

$$\omega_2 = \omega_1 + \alpha t$$

$$\omega_2^2 = \omega_1^2 + 2\alpha t$$

$$\theta = \omega_1 t + \frac{1}{2} \alpha t^2$$

$$\theta = \frac{(\omega_2 + \omega_1)t}{2}$$

$$v = r\omega$$

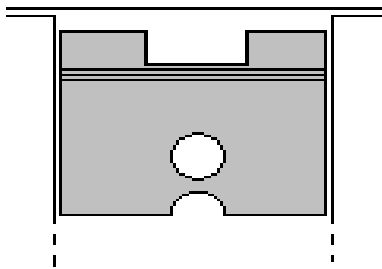
$$a = r\alpha$$

Surface to Volume Ratio

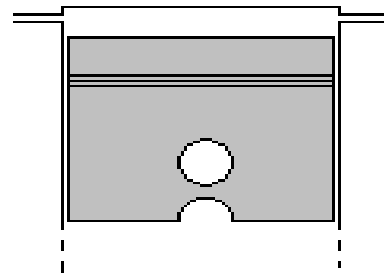
The higher the surface to volume ratio is the more area there is for the charge to condense on and hence the less complete combustion (extreme quench).

Some

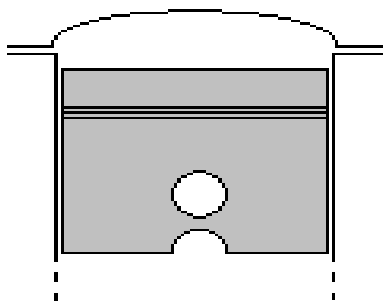
examples:



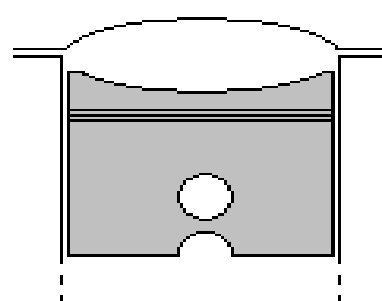
a) Bowl in Piston $s/v = 8$



b) Pancake $s/v = 7.2$



c) Hemisphere $s/v = 6.6$



c) Double Hemisphere $s/v = 6.4$

Results of Improved Swirl and Mixture Homogeneity:

1. Improved flame speed for faster combustion,
2. Faster combustion means lower exhaust gas temperatures, less coking on the valves and lasting flow,
3. Reduced spark timing requirements,
4. Higher net torque,
5. Better emissions due to less unburned hydrocarbons
6. Better fuel economy due to less unburned fuel.

Exhaust Systems

Main Functions:

1. To remove heated exhaust gases away from the cylinders.
2. Reduce noise caused by the engine process.
3. Reduce exhaust emissions.

What is the content of exhaust gases?.....

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Why are exhaust manifolds bad?

Because the exhaust manifold and system restrict the flow of gas away from the cylinders they waste engine power, since the piston has to 'push' the gases out. In order to aid flow and make this restricting less of a hindrance the manifold is manufactured from a series of gentle flowing curves to enable gases to flow more easily away from the cylinder via a smooth route.

Back Pressure.

- Restrictions in the exhaust system slow the exit of gases from the cylinder.
- This keeps high pressure, high temperature exhaust gases near the exhaust valve.
- This pressure resides near the exhaust valve until it next opens, thus impeding the exit of the new exhaust gases leaving the cylinder, further.
- Most of this gas is pushed out by the upward motion of the piston, thus draining power from the engine since it has to do more work to empty the cylinder.
- Some of the gas remains behind in the cylinder diluting the incoming fresh charge, reducing combustion efficiency and hence lowering the potential power further.

But in well-designed systems this pressure can be used to improve the cylinders exhaust cycle...

- In exhaust systems where the primary pipes meet and join together there is an area called the collector. (4 into 2 into 1 OR 4 into 1).
- This high-pressure exhaust gas will travel down the primaries as a high-pressure wave (similar to what occurs when the inlet valve closes in ram tuned inlet systems).
- When this wave reaches the collector it is inverted and becomes a low-pressure wave.
- This low-pressure wave travels back towards the exhaust wave, in preparation for when the valve next opens.
- When the exhaust valve next opens the low-pressure (almost vacuum) aid the removal of gases, as they will move from the high pressure of the cylinder to the low pressure of the manifold.
- This system can be used effectively with valve overlap and ram tuning to help 'suck' new charge into the cylinder in preparation for the next combustion cycle.
- This wave also travels at the speed of sound and we can calculate the distance it travels similar to the ram-tuning wave.
- If the valve overlap is too much the low pressure can suck the fresh, unburnt charge straight into the exhaust. What is this called?.....

Exhaust Systems; Combating Emissions

Catalytic Converters

A catalyst is a substance which increases the rate of chemical reaction without undergoing any permanent change itself. The catalyst must be hot and cannot come into contact with Lead. The air fuel ration is tightly controlled to be stoichiometric.

Three-way converter type, reduce:

- Hydro Carbons.
- CO
- NOx

There are two types of three way converters:

- Reduction Catalyst.
- Oxidation Catalyst.

Both are ceramic structures coated with a metal catalyst which is generally platinum, rhodium &/or palladium.

They have a honeycomb structure that exposes the maximum amount of surface area of catalyst to the maximum quantity of exhaust gas, whilst minimising the amount of catalyst needed.

Reduction Catalyst.

- Uses platinum and rhodium to reduce NOx.
- When NO or NO₂ molecules contact the catalyst the nitrogen reacts, leaving only O₂ in the exhaust stream to exit to atmosphere.
- The Nitrogen remains in the catalyst as N₂.
- $2\text{NO} \longrightarrow \text{N}_2 + \text{O}_2$
- $2\text{NO}_2 \longrightarrow \text{N}_2 + 2\text{O}_2$

Oxidation Catalyst.

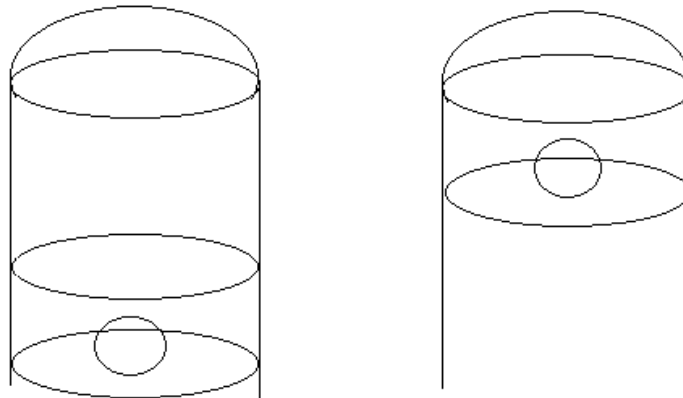
- This reduces the unburned hydrocarbons and CO by oxidising them in a Platinum and Palladium catalyst.
- This causes a reaction of CO and HC with the remaining oxygen in the exhaust gas.
- $2\text{CO} + \text{O}_2 \longrightarrow 2\text{CO}_2$
- $4\text{HC} + 5\text{O}_2 \longrightarrow 2\text{H}_2\text{O} + 4\text{CO}_2$

Exhaust Gas Recirculation (EGR).

This is a technique where by NO_x emissions are reduced by filtering a fraction of the exhaust gas stream through a control valve into the intake system. Thus recycles exhaust gas is mixed with the fresh air/fuel charge at part load throttle settings diluting the mixture. This reduces the peak burned gas temperatures and hence the NO_x formation rates.

Compression ratio

A compression ratio is just a ratio of two different volumes:



Initial Volume, V_1

Final Volume, V_2

Compression ratio, $r = \frac{V_1}{V_2}$ OR $r = \frac{CV + CCV}{CCV}$

Where CV is the cylinder volume and CCV is the combustion chamber volume.

How do we measure/ calculate CV and CCV?

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What is not taken into account at this point?.....

Volume of the cylinder head gasket (assuming flat top pistons):

$$V = \frac{\pi D^2 H}{4000}$$

Where:

D, is the diameter of the bore (mm)

H, is the compressed thickness of the gasket or the clearance between the piston crown and the block deck.

Typical values:

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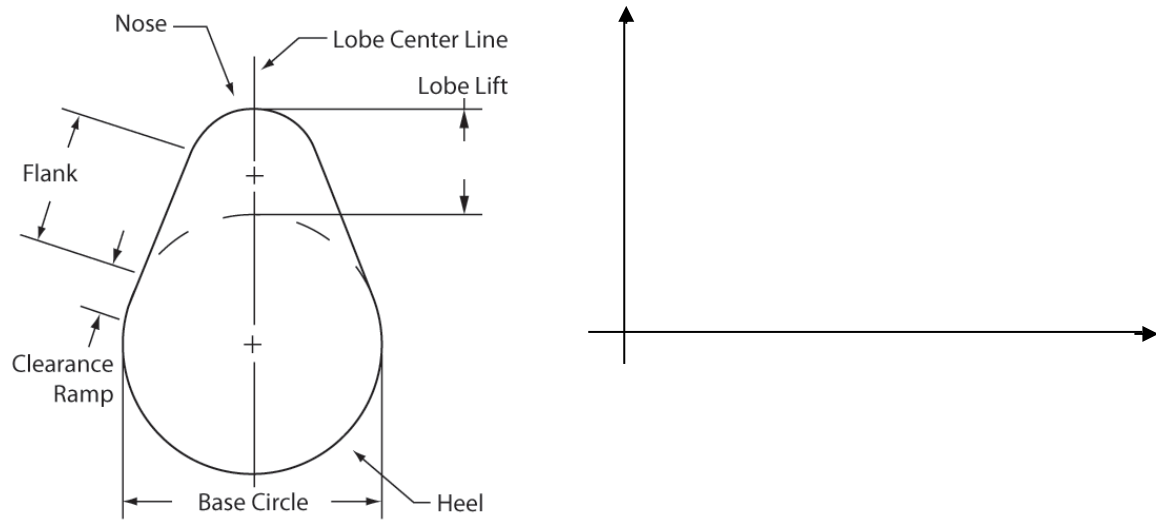
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Camshafts

Duration: Number of degrees of engine rotation that the valves are open (off their seats).

Lift: The amount the valves are opened by.



(Lunati, 2016)

Draw on the axis supplied a graph of Valve lift (mm) versus cam angle (degrees), marking on it the regions where:

- Spring control is highest, this is where the camshaft accelerates the valve to its maximum velocity.
- The camshaft accelerates the valve on the ramp and eases it back onto its seat (base circle).

Draw two examples of poor cam profiles:

Production car (petrol) profile:

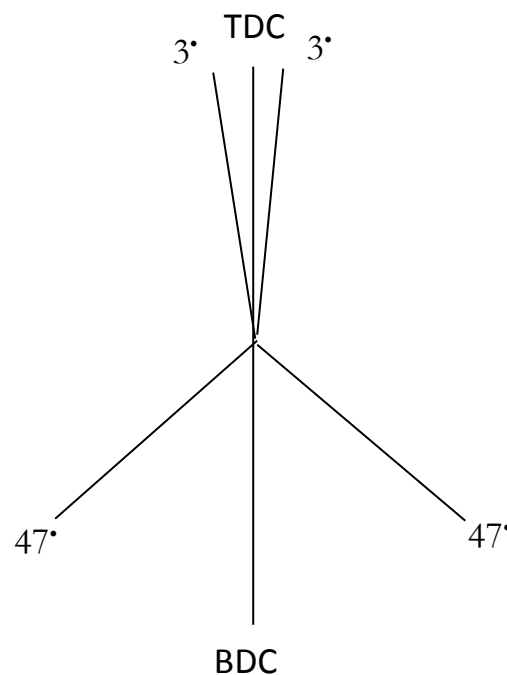


- Inlet valve must close soon after BDC to keep compression up.
- Too large overlap is detrimental to part throttle and idle as pressure back flows from the exhaust, reducing the induction pressure.
- At full load, lots of overlap is bad for fuel economy, as fuel is sucked straight through to the exhaust without combustion.
- All of the above is dramatically improved by direct injection.

Camshafts rotate at half the speed of the crank (engine speed), so the power stroke only sees one fourth of the turn of the cam or 90degrees cam angle.

Traditionally we show profiles using cam wheel diagrams:

Production car (petrol) profile:



Now draw your own wheel diagrams for the following:

	Diesel	Mild Race	Nascar
Inlet Opens	5	20	60
Inlet Closes	45	50	70
Exhaust Opens	40	60	90
Exhaust Closes	10	10	40

Honda VVT

Variable valve timing essentially alters the following two characteristics of an engine:

- The valve duration.
- The valve lift.

SOHC Type VTechE.

- 16 valve.
- It has four lobes and 4 rockers per cylinder.
- Two of each of these are for the exhaust valves, are not variable I.e. they have fixed valve duration and lift.
- The other two of each of these are for inlet valve actuation.
- One valve opens further than the other at low rpm.
- At high rpm they both follow the larger lobe profile on the cam.
- One inlet open significantly further than the other at low rpm ranges, the other opens enough to prevent pooling of the fuel behind the valve.
- At higher rpm, the ECU signals the opening of a valve at the end of the rocker shaft which allows oil to flow through the shaft to a mini piston within the inlet rockers; this piston pushes a solid pin through to the adjacent rocker engaging it to follow the larger profiled lobe on the cam.
- The VTechE is effectively a single inlet valve engine at low rpm and a twin inlet valve engine at high rpm.
- This system merely increases low rpm charge velocity, conserving fuel and improving burn, but giving no significant power gain.

SOHC Type VTech.

- 16 Valve.
- 5 cam lobes and 5 rocker arms.
- 2 Exhaust lobes and rockers which follow one type of profile for all of the rpm range.

- At low to mid range engine speeds the rocker arms are aligned with the outer two lobes, directly opening and closing valves.
- At these low rpm values the middle rocker is essentially a follower simply following its profile but not opening any valves.
- At higher rpm values (between 5000 & 6000 rpm typically) the ECU sends a signal to a valve which opens allowing oil to flow through the rocker shaft activating a piston which engages a pin into the 3rd rocker, thus connecting all three rockers forcing the two outside to follow the middle rocker profile which is larger and longer than the original profiles.
- This system optimises the flow of charge for high rpm operation, but maintains a smooth and economical low rpm operation.

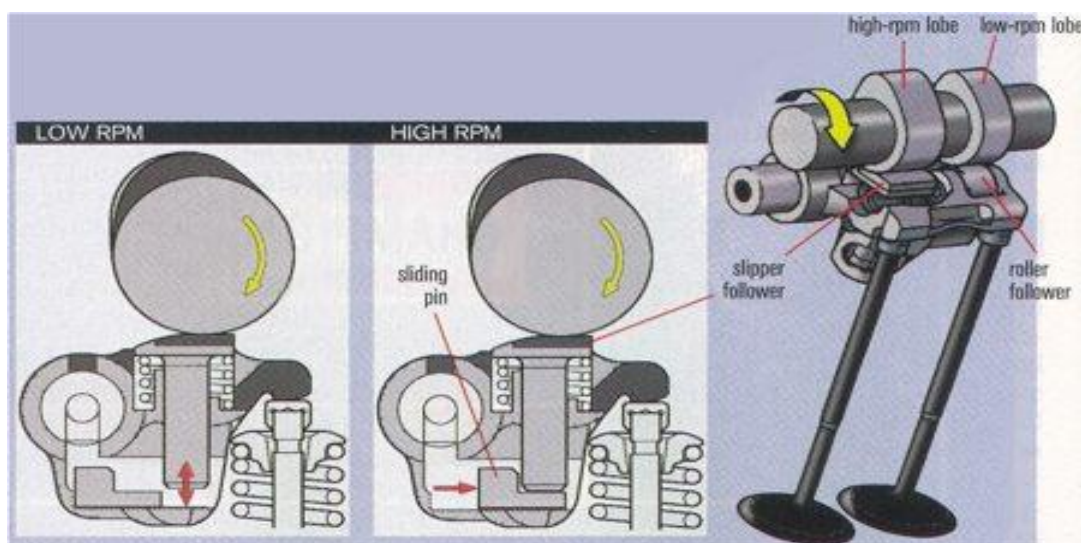
DOHC Type VTech.

- 2 Camshafts.
- 16 valves.
- Each camshaft activates 2 valves per cylinder, and has 3 rockers and 3 lobes per cylinder.
- As before the valves follow a mild cam profile at low- mid range rpm.
- During this time the middle rocker serves no purpose and acts as a follower not opening any valves.
- At higher engine speeds a signal from the ECU activates a valve allowing oil to flow through the rocker shaft activating a mini piston that slides a pin through the two outside rockers engaging them to follow the longer/ larger profiled lobe.
- This improves engine breathing at high rpm, sustaining torque and power output as rpm rises.
- But it also retains a smooth and economical operation at low engine speeds.

More Variable Valve Timing Variations

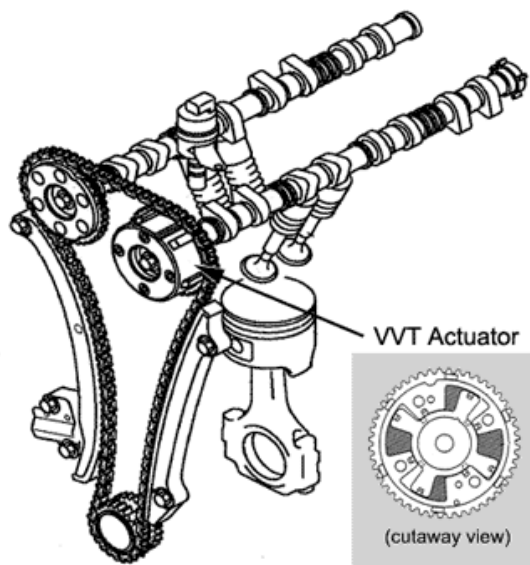
Toyota.

- The following is on Toyota's Variable Valve Timing and Lift (with intelligence) system.
- The VVL portion of the system is similar to Honda's VTEC system, incorporating two distinct cam profiles. However, the actual mechanism is quite different.
- Both cam lobes operate a single wide rocker arm that acts on both intake or both exhaust valves.
- A needle-bearing roller on the arm follows the low-rpm, short-duration, low-lift lobe, forcing both valves to open and close on that profile. The roller design and roller bearings on the rocker arm pivot help to minimise valvetrain friction.
- The high-rpm, higher-duration, longer-lift lobe rubs on a hardened steel slipper follower mounted to the rocker arm with a spring. Even though the high-rpm lobe is pushing down further than the low-rpm lobe, the spring absorbs the extra movement.
- At 6000rpm, the ECU sends a signal to an oil control valve at the end of the camshaft that puts oil pressure behind a lock pin in the rocker arm, sliding the pin under the spring-loaded slipper follower, locking it to the rocker arm and forcing the arm to follow the high-rpm cam profile.



Mazda Engine Technology.

- 2.3l & 3.0l engines share technology but work very differently.
- Both engines are made from the Ford Duratec block but have been up-graded for high revving performance.
- The engines make use of four different induction technologies:
 - ✦ VAD, Variable Air Duct.
 - ✦ VLIM, Variable Length Intake Manifold.
 - ✦ VTCS, Variable Tumble Control System.
 - ✦ VVT, Variable Valve Timing (Intake valves only).
- VAD technology employs a second air duct prior to the filter which opens after 4500rpm. When this second air duct opens on one the side of the air box, a larger volume of air is given a shorter and quieter route to the engine. This enables the vehicles to comply with EU noise regulations.
- The VVT and VLIM are designed to broaden the torque band of the engine. i.e. they give more torque throughout the rev range.
- For the VVT Mazda use one camshaft attached to a cog that is controlled by a precision oil pump. This pump advances or retards the cog and hence the camshaft so the valves can open sooner or later depending on the load put on the engine. (not to be confused with longer or further opening, it simply changes the time when the valves are opening in the engine cycle).



- The VLIM is an electronically operated system which alters the volume of its intake runner lengths, thus changing the frequency of the charge. Generally a system integral to the air box which has two routes through it which enhance ram tuning at specific rev ranges, and are activated by a flap. The change occurs at 4500rpm, each tuned to return a pulse wave at a different rpm.
- Using a combination of the VVT and the VLIM the engines can be tuned for different applications, such as low rpm power (truck engines and towing vehicles) and high rpm power fast road vehicles. Whilst these systems enhance the torque curve they do not broaden it as much as the Honda VTech system enables.
- The VTCS is designed to help lower emissions at low rpm. A shutter valve in the intake closes part of the pathway of charge off, increasing the velocity of the charge. This speed gives the charge more inertia to swirl thoroughly mixing the charge ready for combustion. It is related to the valve opening, at low opening, charge is already accelerated by the valves, but at high lifts (VVL) the charge speed is encouraged with the valve at low rpm. It disengages at 3750rpm.
- So in summary the Mazda system offers top end power through its VVT and low to mid-range torque from the VLIM.

Another system worth looking at is the Ducati Desmotronic.