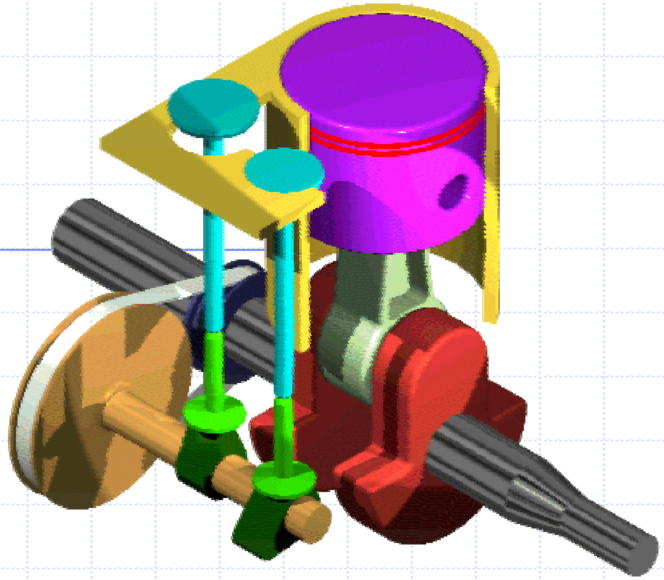
Valve Design and Variable Valve Timing Technology



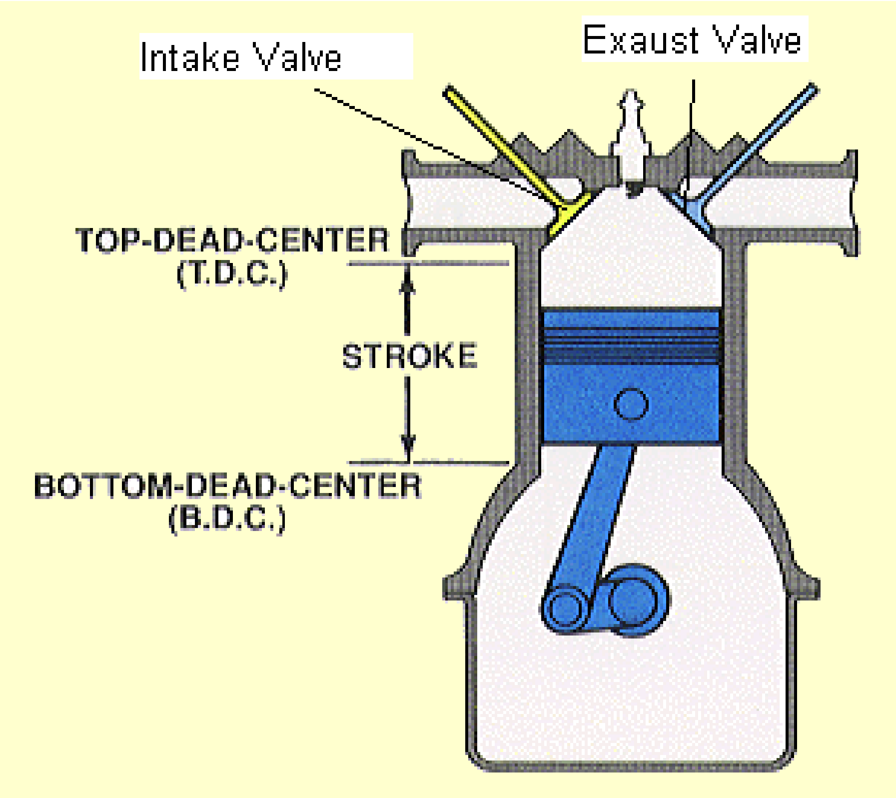
Richard Trotta

October 5, 2001

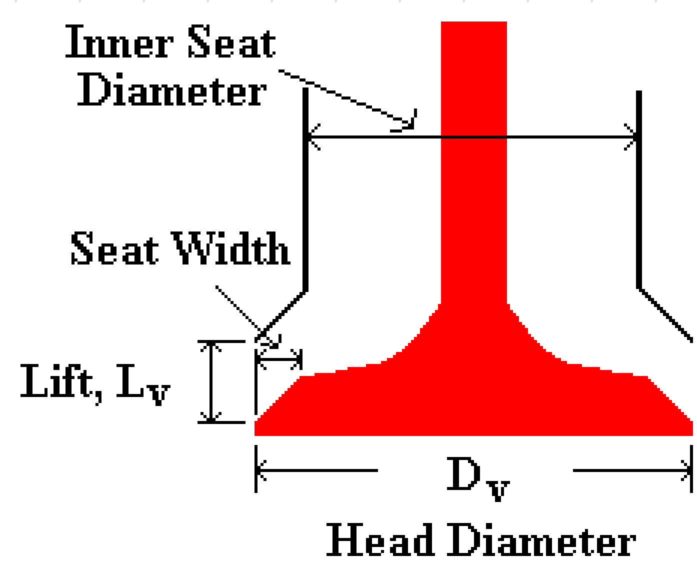
Outline

- Valve Basics
  - Function
  - Control
- Valve Dynamics
- Multiple Valve Design
- Valve Timing
  - Intake
  - Exhaust
  - RPM
- Variable Valve Timing
- ESP Program

Valve Basics

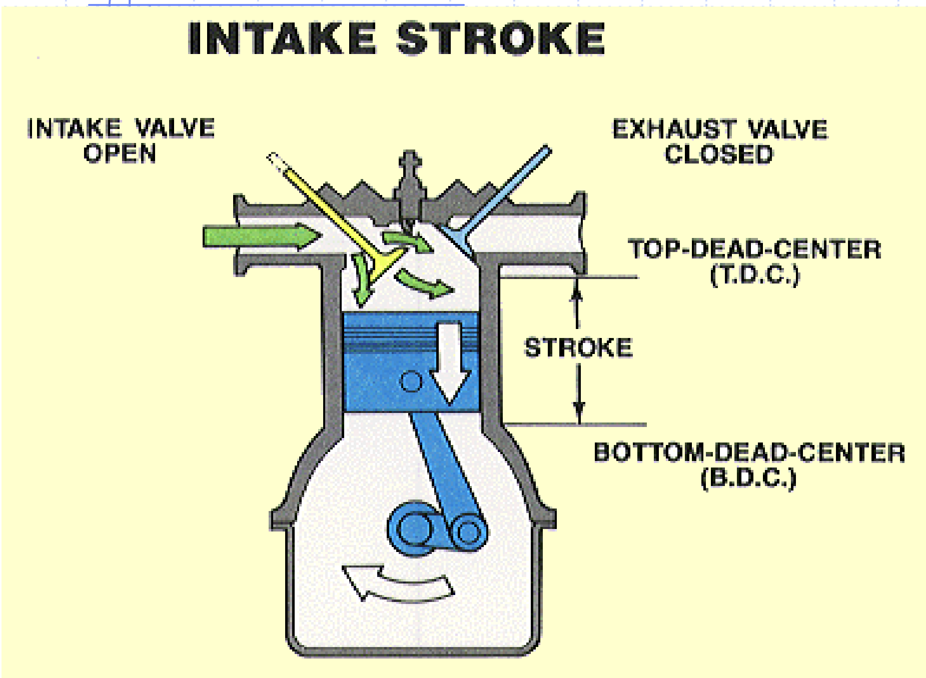


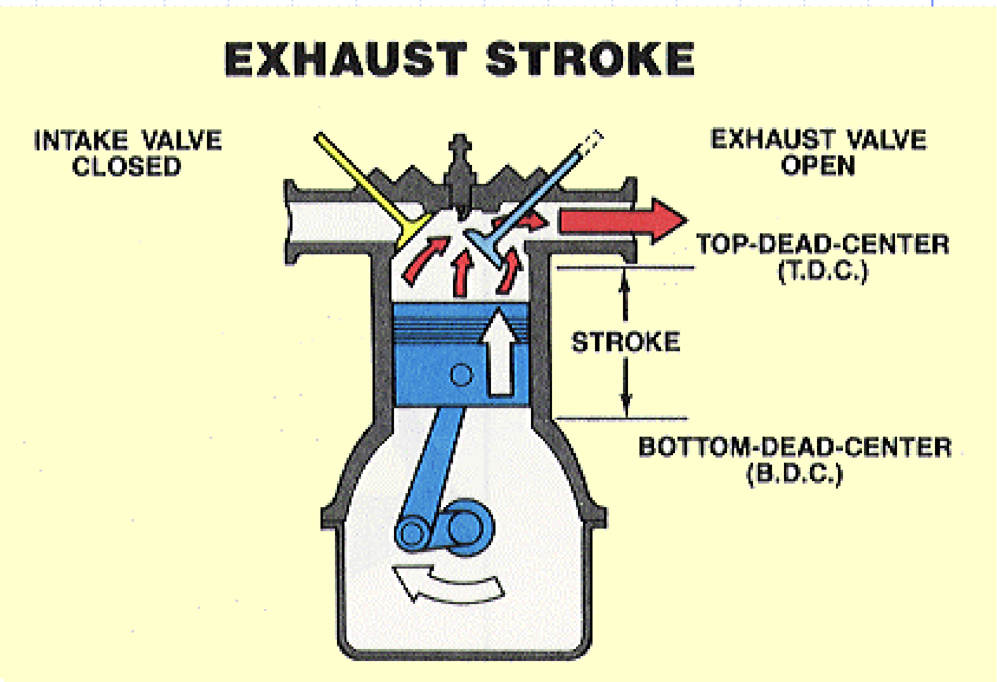
Location



Dimensions

Valve Function



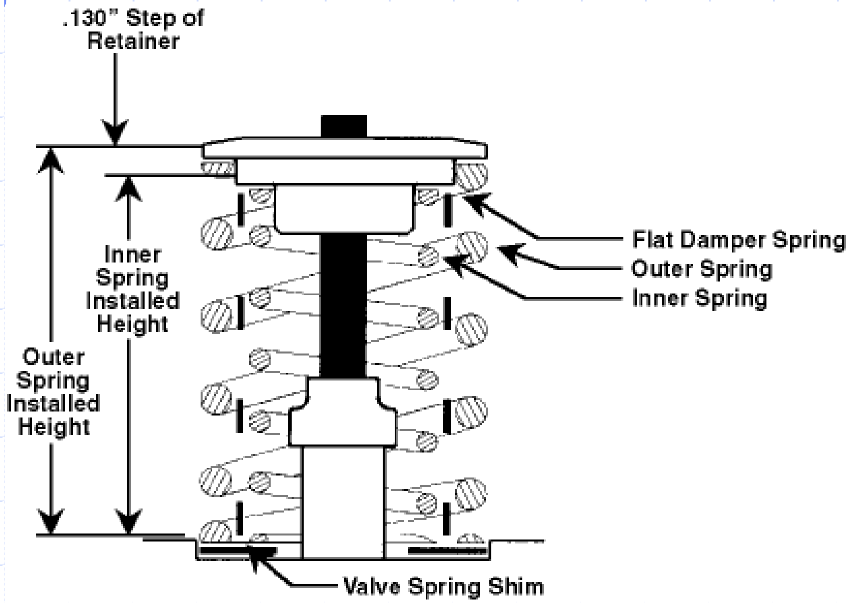


Valves allow the engine to breath. The intake valve allows air and fuel into the cylinder so combustion can take place. The exhaust valve releases the spent fuel and air mixture from the cylinder.

Valve Control

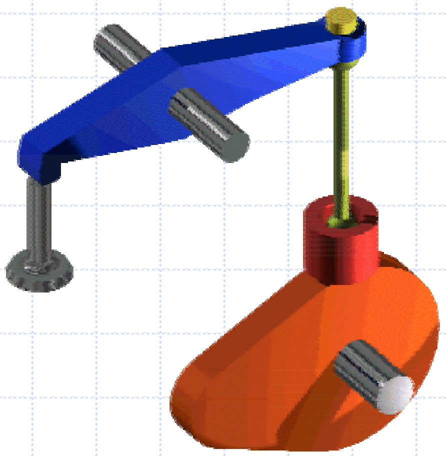
Springs

Springs are used to keep the valves in place and to provide the force needed to close the valve.



Must be strong enough to keep the valve in contact with the cam. At high engine speeds.

Valve Control



Cams

Cams driven by the engine provide the force to push the valves open, usually by way of a rocker arm. The shape of the cams determine the timing and distance the valves travel

Because of the springs the cam friction can contribute 25% of the total friction in the engine.

Rocker Arms

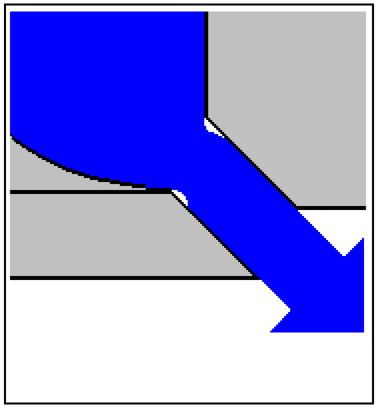
Show above in blue these are the links between the cam and the valve.

Valve Dynamics

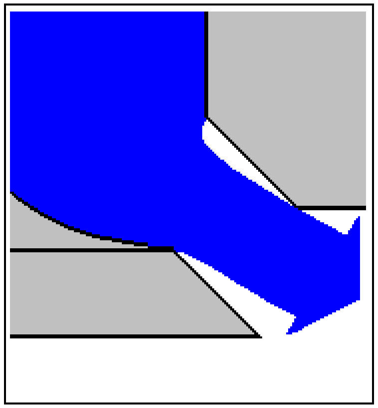
Flow Dynamics

- Choke in bad and is a major limitation to piston speed.
- Mainly a concern with the intake

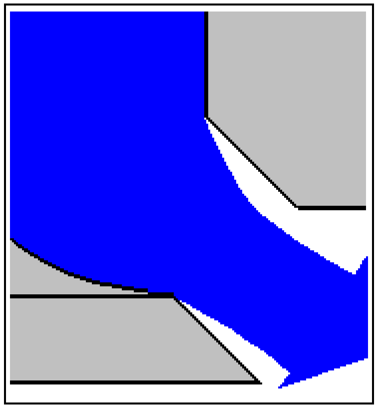
Valve Lift



Low Lift

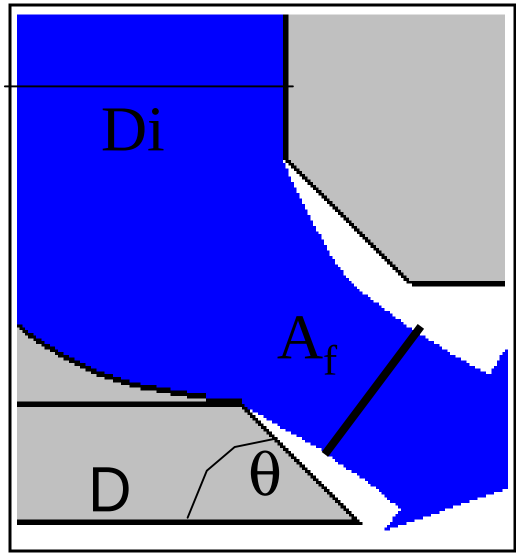


Intermediate Lift



High Lift

Flow Area



$$A_f = \pi D L \frac{1+\frac{D_i}{D}}{2} \cos\theta$$

At high lift the smallest area is the port area.

Maximum Lift

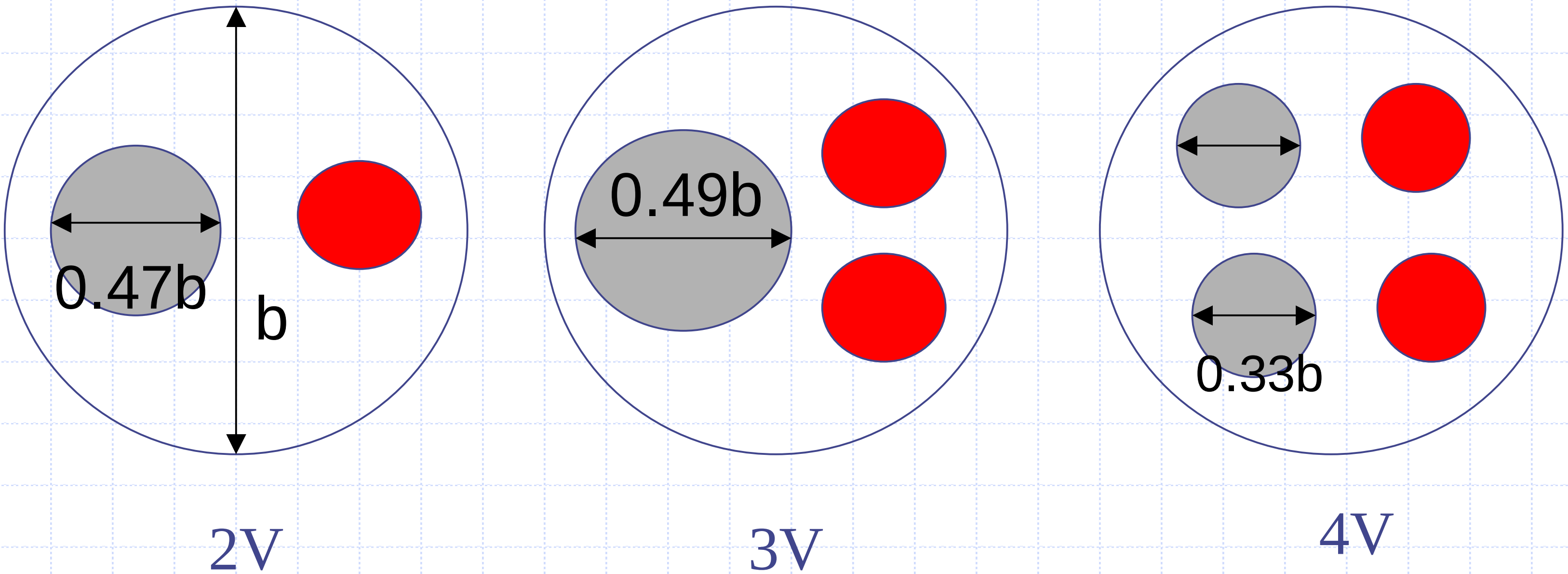
By setting the port area equal to the flow area you can find the maximum lift.

$$L = \frac{D}{4} \frac{\left(\frac{Di}{D}\right)^2}{\cos\theta \frac{1+\frac{Di}{D}}{2}}$$

Rough Estimate

$$L = \frac{D}{4}$$

Multiple Valve Design



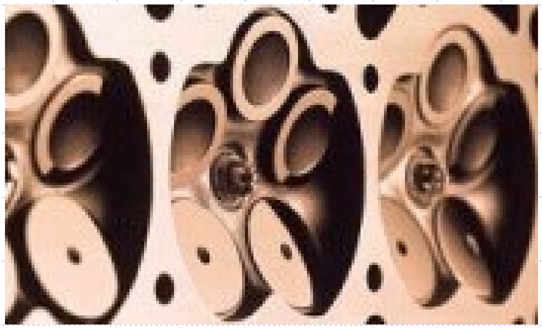
2V $A_{intake} = \frac{\pi}{4} 0.47^2 = 0.173$

3V $A_{intake} = \frac{\pi}{4} 0.49^2 = 0.189$

4V $A_{intake} = 2(\frac{\pi}{4} 0.33^2) = 0.171$

Based on area 3V should Be the best.

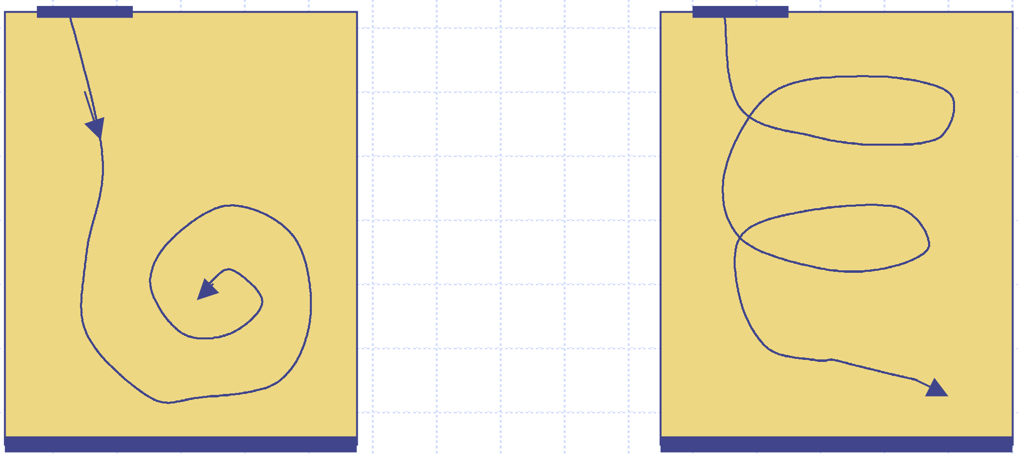
Multiple Valve Benefits



5V Ferrari Engine

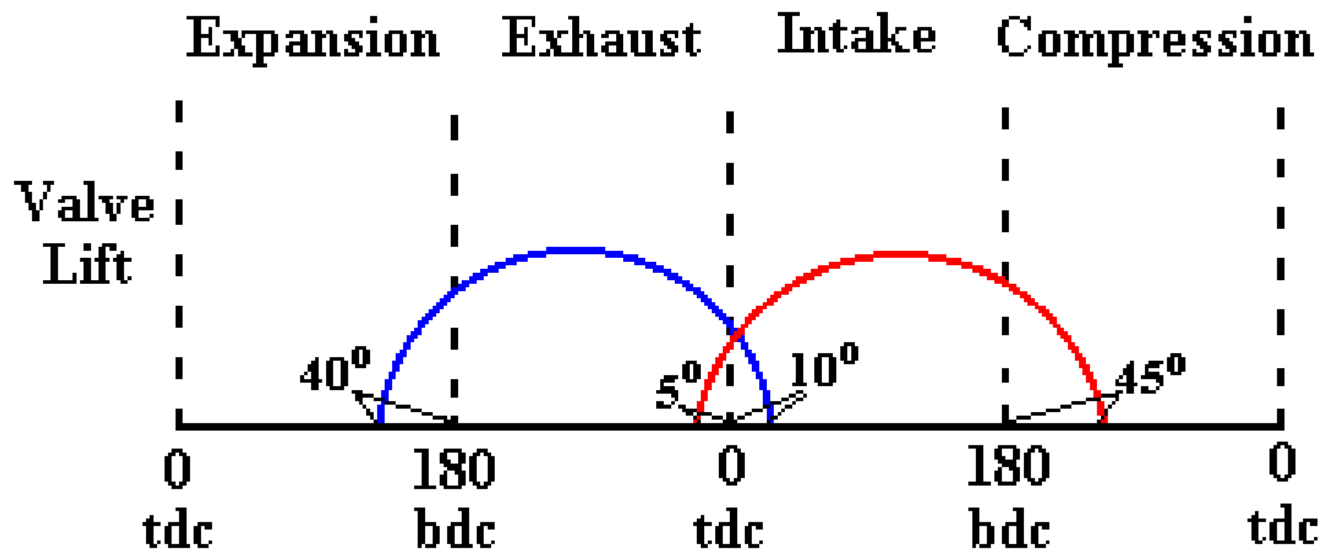
- Different length runners to each valve
- Increased turbulence and mixing of fuel and air
    - Swirl
    - Tumble
- Valve timing benefits

Tumble and Swirl



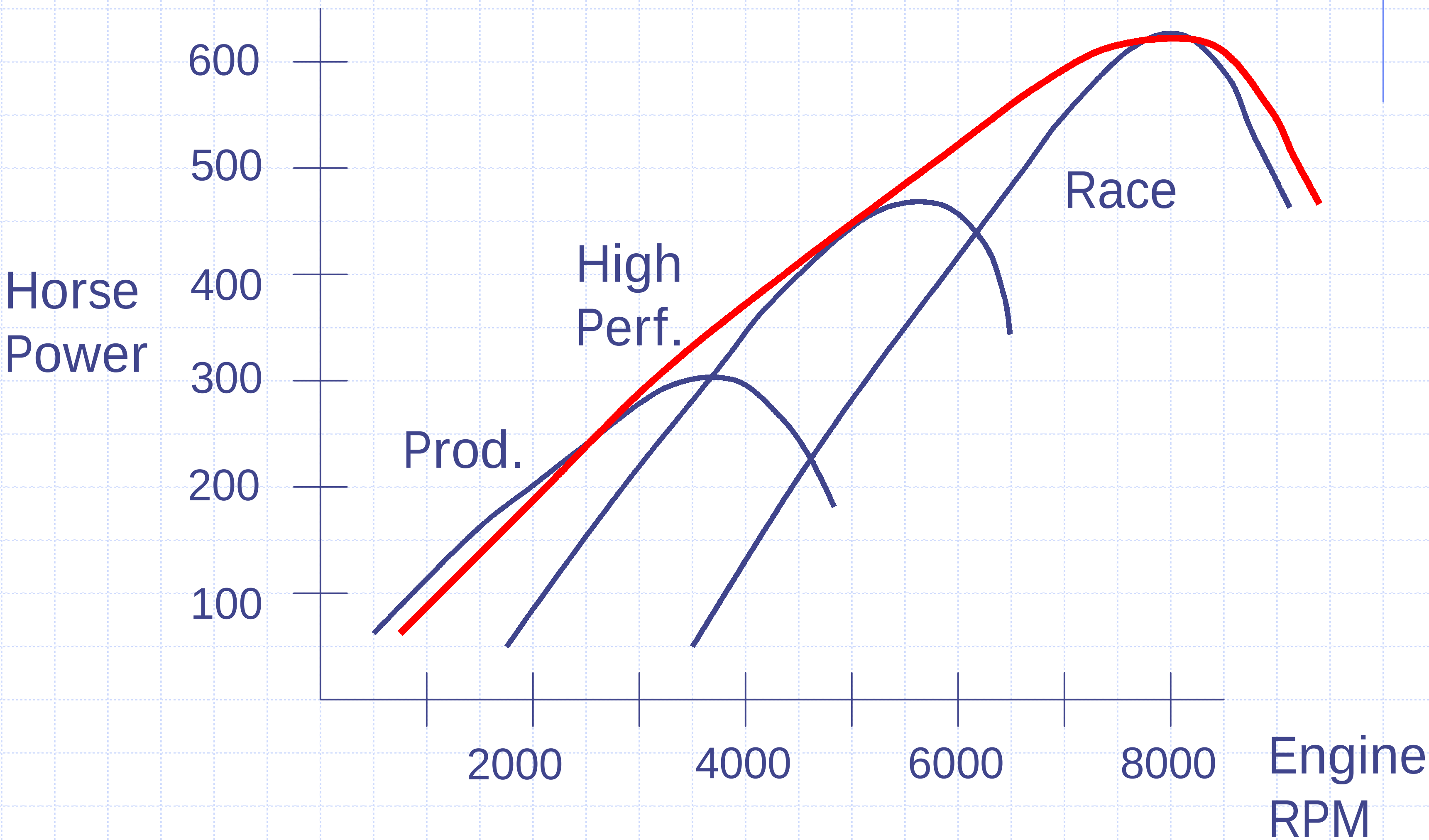
- Valve ports or the valves themselves can cause swirl
- Tumble and swirl can also be generated by timing

Valve Timing



- Intake opens before TDC so there will be a large area for induction
- Exhaust opens before BDC to give exhaust time to escape

Power

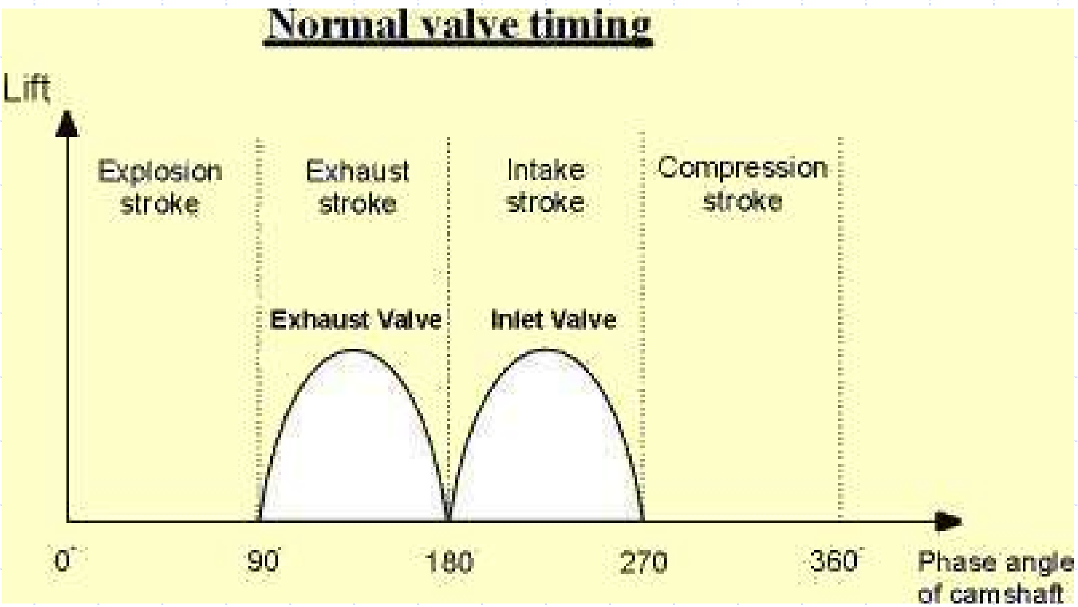


Horse
Power
600
500
400
300
200
100
Prod.
High
Perf.
Race
2000
4000
6000
8000
Engine
RPM

The Great Compromise

At partial throttle, low RPMs, the pressure in the intake is lower than the exhaust pressure so exhaust gases will flow into the intake.

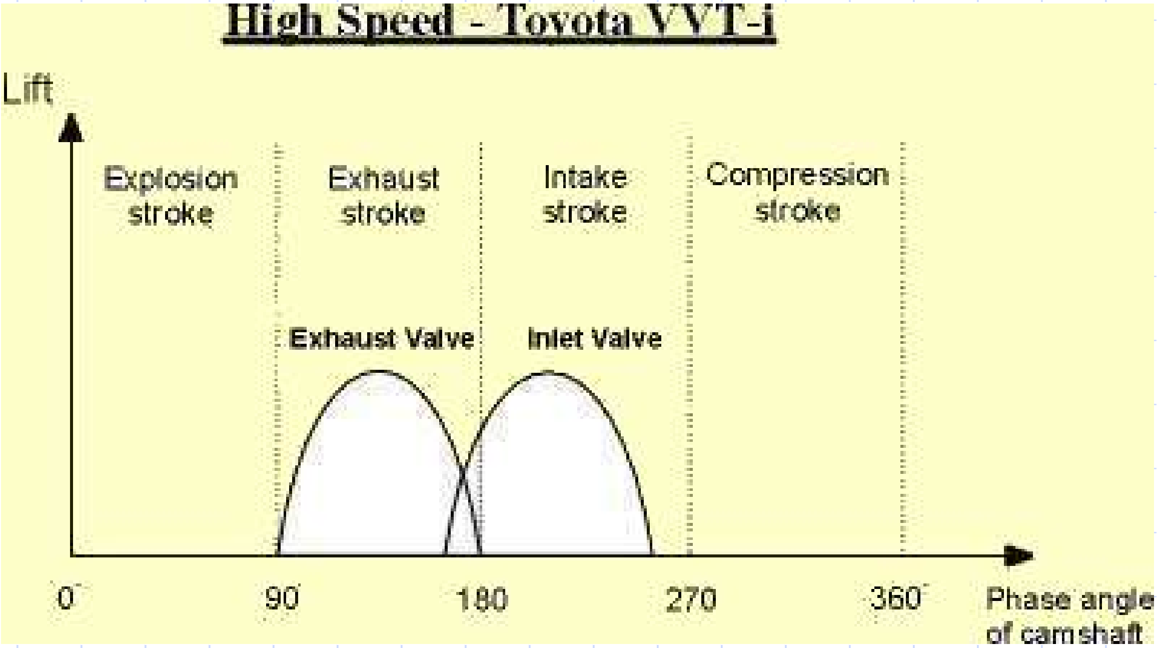
At low RPMs the exhaust needs to open earlier so there is not much overlap.



A compromise must be made.

High RPM

At high RPMs the exhaust is at a higher pressure than the intake so it will help draw air in.



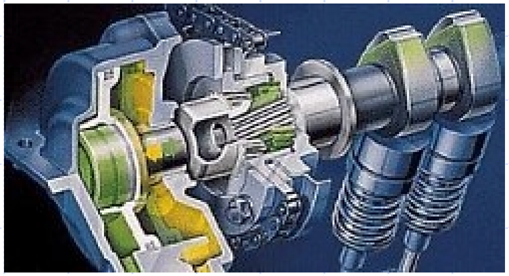
- There is a limit to the valve lift.
- To get more air in the valve needs to stay open longer.
- High RPMs you want the exhaust valves to open later.

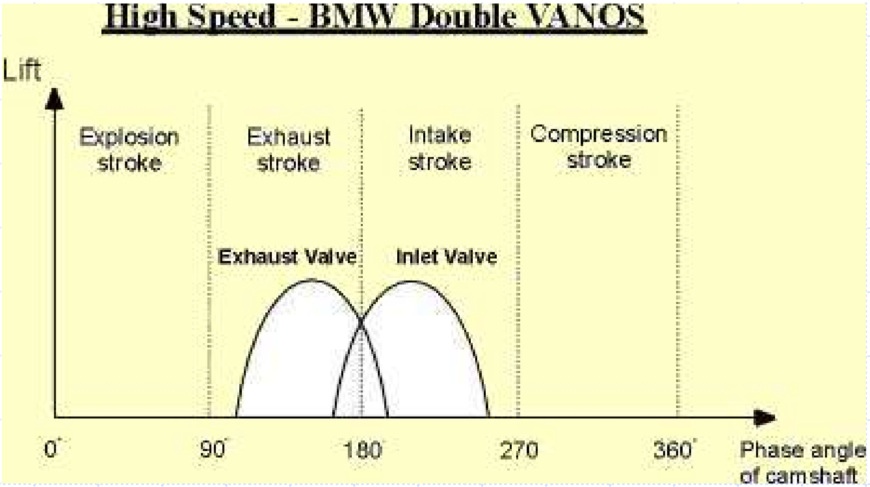
The Solution
VVT

As engine speeds increase allow more overlap between the intake and the exhaust.

Cam Phasing

BMW Double Vanos

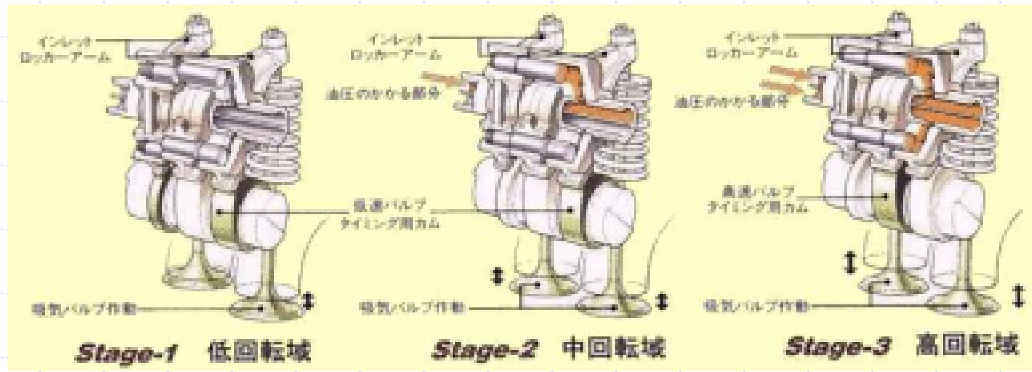




- Simple and inexpensive
- Continuous
- Least performance gain of VVT systems

More VVT

3 Stage Honda VTEC

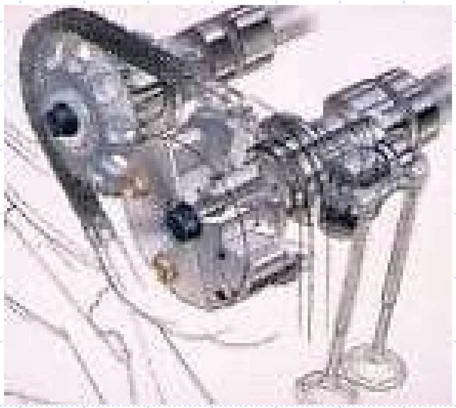


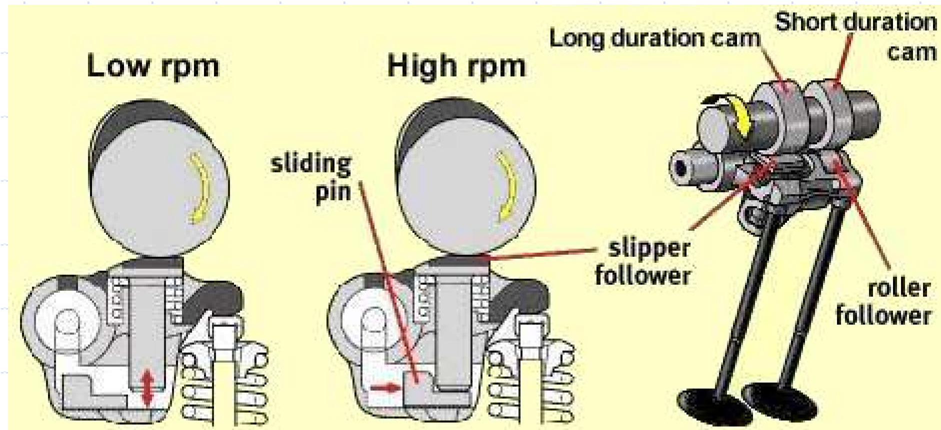
Cam Changing

- More performance than cam phasing
- More complicated
- Not continuous

VVTL-i

Toyota





Cam Phasing and Cam Changing

- Continuously variable timing
- 2-Stage variable lift and duration
- Applied to both intake and exhaust

Most Advanced VVT

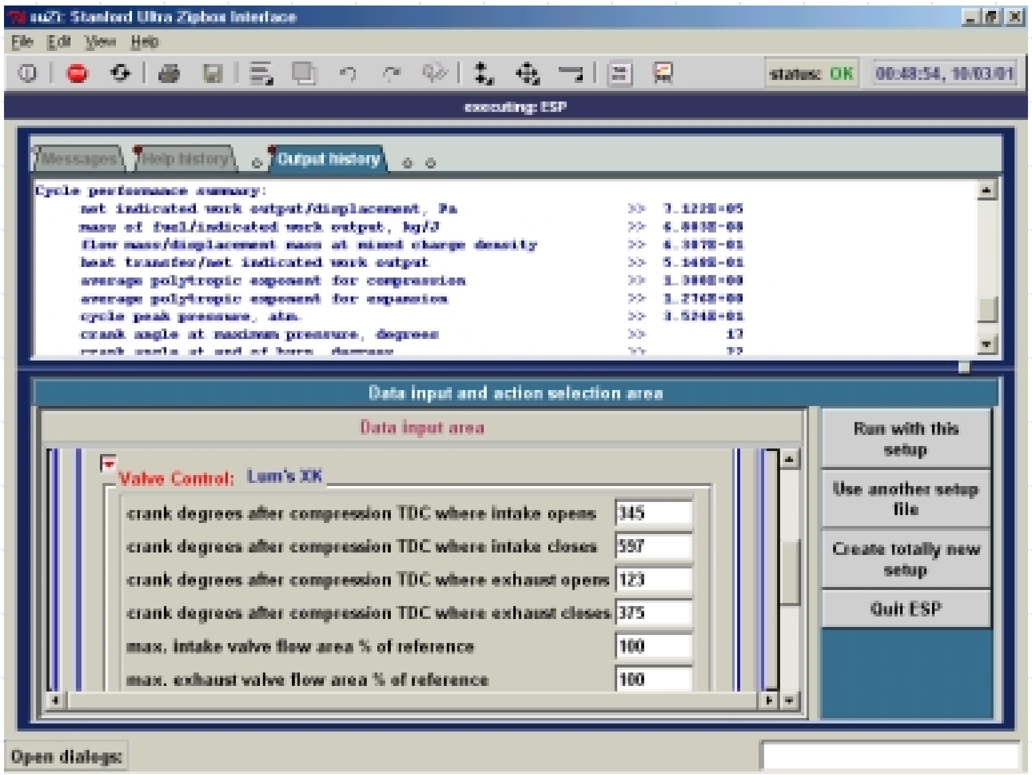
Rover VVC

- Continuously variable timing and lift.
- Complex and large

Lotus Active Electro-Hydraulic Valves

- Continuously variable lift and timing
- No springs
- Expensive $1000 per valve

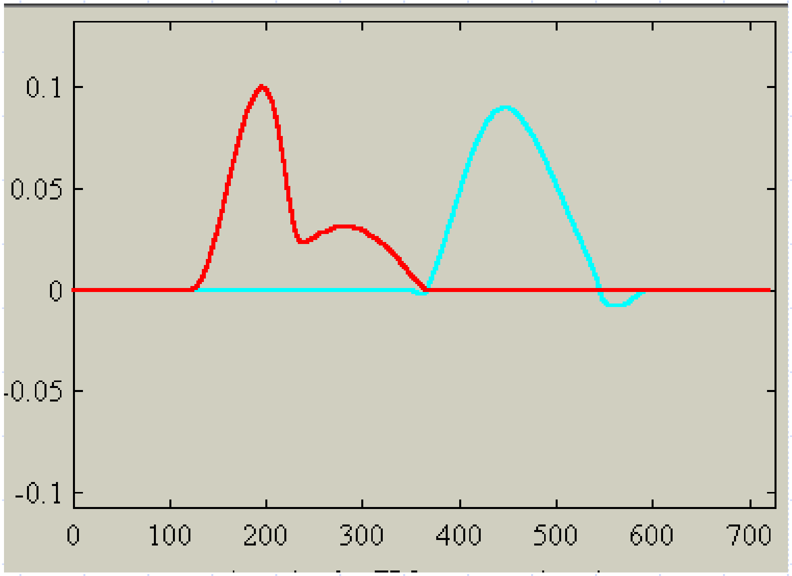
ESP Program



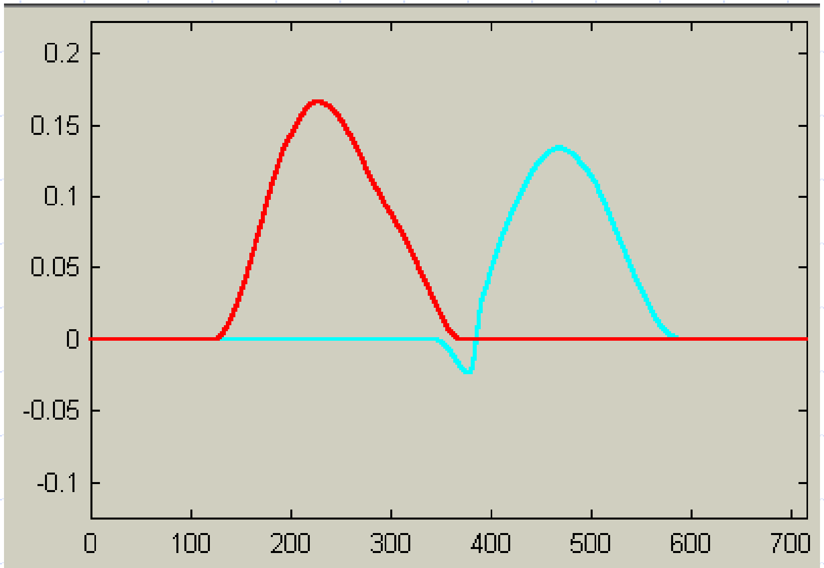
Using ESP you can run the engine at different RPMs and see the effect on performance.

You can also use ESP to examine valve timing.

More ESP



Mass flow rates at 2400 RPM

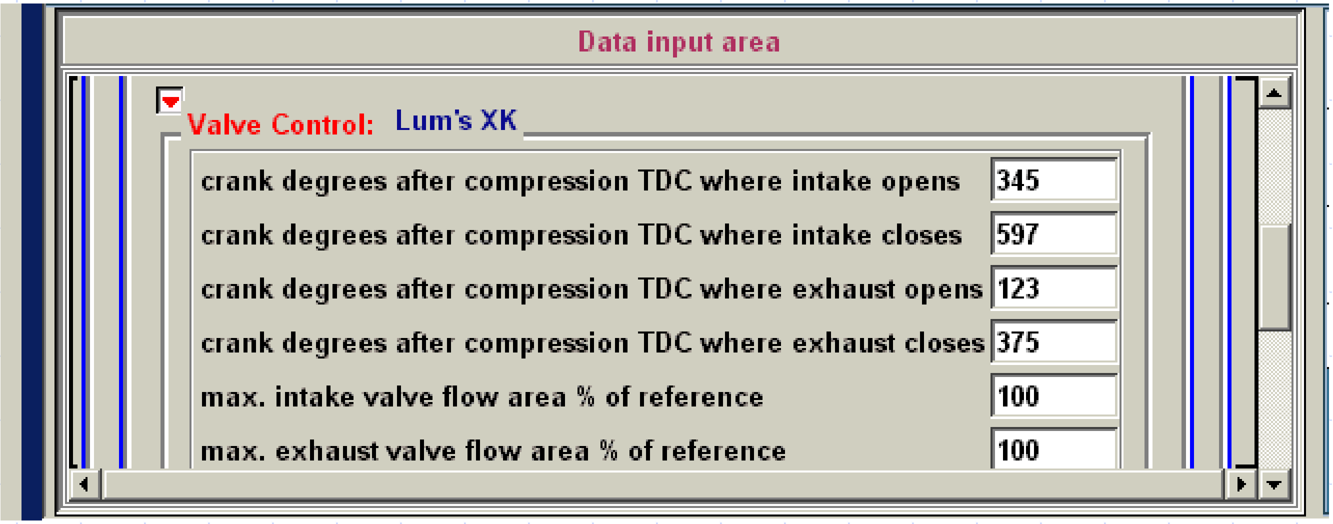


Mass flow rates at 6000 RPM

ESP can also generate graphs of the mass flow rates.

- Notice the two peaks in the exhaust flow rate at 2400 RPM.
- Also notice the negative flow rate in the intake at 6000 RPM.

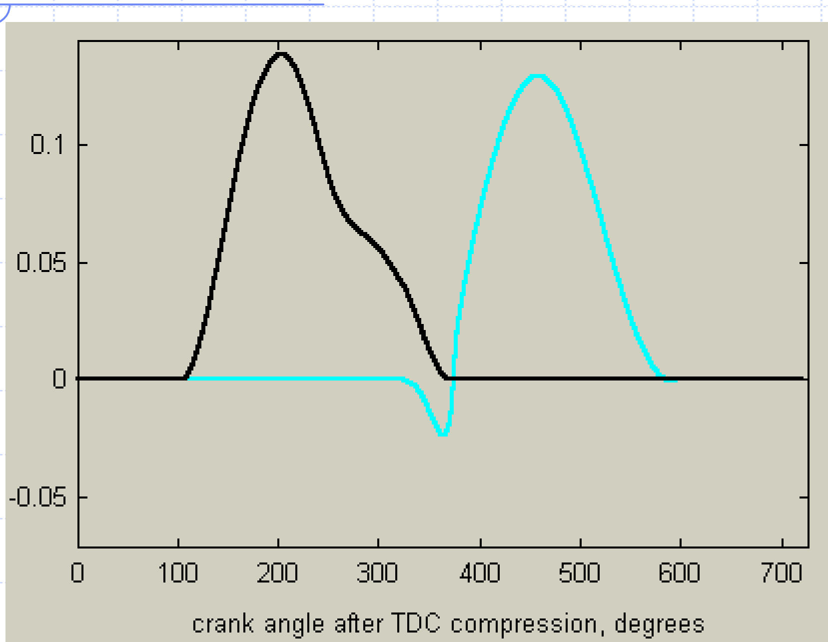
ESP and Valve Timing



The picture above show the valve control options in ESP

Now lets examine some results from ESP.

Normal Timing

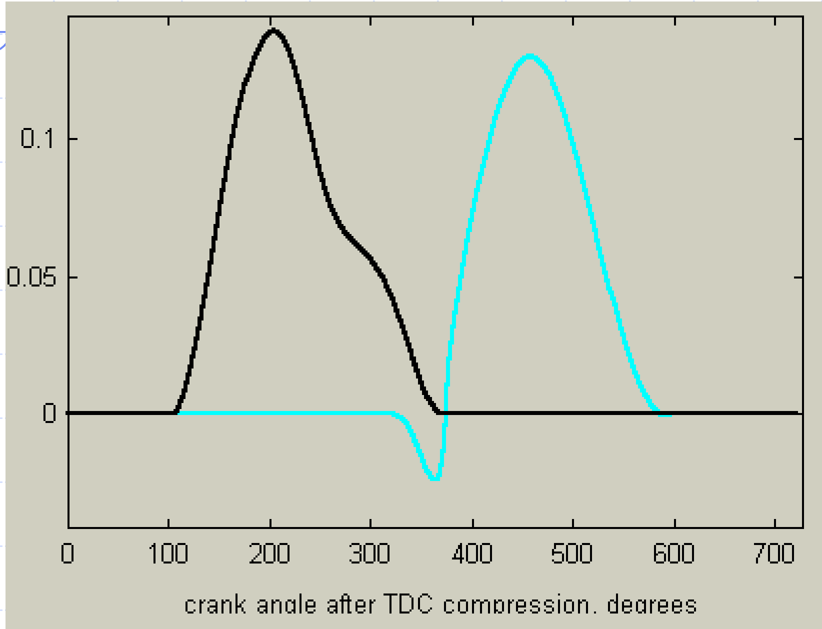


ank degrees after compression TDC where intake opens	345
ank degrees after compression TDC where intake closes	597
ank degrees after compression TDC where exhaust opens	123
ank degrees after compression TDC where exhaust closes	375
ax. intake valve flow area % of reference	100
ax. exhaust valve flow area % of reference	100

5000 RPM

```
Cycle performance summary:
    net indicated work output/displacement, Pa              >>   8.522E+05
    mass of fuel/indicated work output, kg/J                >>   6.657E-08
    flow mass/displacement mass at mixed charge density     >>   7.385E-01
    heat transfer/net indicated work output                 >>   5.159E-01
    average polytropic exponent for compression             >>   1.311E+00
    average polytropic exponent for expansion               >>   1.280E+00
    cycle peak pressure, atm.                               >>   4.079E+01
    crank angle at maximum pressure, degrees                >>          17
    crank angle at end of burn, degrees                     >>          21
    mixed exhaust temperature at valve exit, K              >>        1395
```

Earlier Exhaust and Earlier Intake



crank degrees after compression TDC where intake opens	325
crank degrees after compression TDC where intake closes	597
crank degrees after compression TDC where exhaust opens	103
crank degrees after compression TDC where exhaust closes	375
max. intake valve flow area % of reference	100
max. exhaust valve flow area % of reference	100

5000 RPM
More Power
Greater Volumetric Efficiency

Cycle performance summary:

net indicated work output/displacement, Pa	>>	9.012E+05
mass of fuel/indicated work output, kg/J	>>	6.438E-08
flow mass/displacement mass at mixed charge density	>>	7.553E-01
heat transfer/net indicated work output	>>	4.751E-01
average polytropic exponent for compression	>>	1.314E+00
average polytropic exponent for expansion	>>	1.268E+00
cycle peak pressure, atm.	>>	4.224E+01
crank angle at maximum pressure, degrees	>>	17
crank angle at end of burn, degrees	>>	21
mixed exhaust temperature at valve exit, K	>>	1402