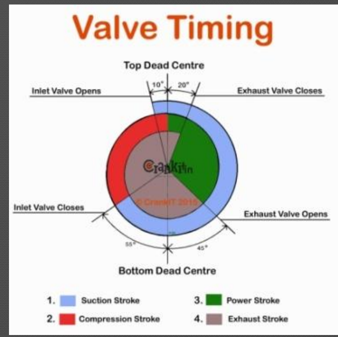


VARIABLE VALVE TIMING

ME 3504: Electronic Management of Engines

Clint Antony
131501008

Variable Valve Timing

- It is the process of altering the timing of a valve lift event, and is often used to improve performance, fuel economy or emissions.
- There are many ways in which this can be achieved, ranging from mechanical devices to electro-hydraulic and camless systems.

The Need ..

- Valves control the breathing of the engine – controls the flow of intake and exhaust gases in and out of the combustion chamber.
- Without variable valve timing, the valve timing (w.r.t a reference in a cycle) will be same for all engine speeds and conditions which can greatly affect the performance.
- As the speed of the engine becomes higher, the valves tend to open and close very quickly allowing less amount of air to enter into the combustion chamber. (solution: racing cam)
- But in order to increase the inlet valve open duration, advancing the opening of the inlet valve increases the valve overlap duration causing the unburnt fuel to escape the engine causing pollution and low performance.

Valve Overlap

LESS	MORE
• Smooth idle • More slow speed torque. • Less scavenging (HS)	• Better engine breathing (HS) • Rough idle (dilution of mixture) • Higher exhaust emissions (LS)

Effects of Timing Adjustment

- ***Late intake valve closing:***
  - Reduces pumping loses by 40% during partial load conditions
  - Decrease nitric oxide (NOx) emissions by 24%.
  - Peak engine torque showed only a 1% decline
  - Hydrocarbon emissions were unchanged.

- ***Early intake valve closing:***
  - Early intake valve closing reduces pumping losses by 40%
  - Increases fuel economy by 7%.
  - It also reduced nitric oxide emissions by 24% at partial load conditions.
  - A possible downside to early intake valve closing is that it significantly lowers the temperature of the combustion chamber, which can increase hydrocarbon emissions.

Source:Hong, H. (2004). Review and analysis of variable valve timing strategies - eight ways to approach. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 218(10), 1179-1200.

Effects of Timing Adjustment

- ***Early intake valve opening:***
- Early intake valve opening is another variation that has significant potential to reduce emissions.
- Controls the temperature and hence the NOx emissions.
- Improves volumetric efficiency, because there is less exhaust gas to be expelled on the exhaust stroke.

- ***Early/late exhaust valve closing:***
- Early and late exhaust valve closing can also reduce emissions.
- By holding the exhaust valve open slightly longer, the cylinder is emptied more and ready to be filled with a bigger air/fuel charge on the intake stroke.
- By closing the valve slightly early, more exhaust gas remains in the cylinder which increases fuel efficiency. This allows for more efficient operation under all conditions.

Hong, H. (2004). Review and analysis of variable valve timing strategies - eight ways to approach. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 218(10), 1179-1200.

Methods of Implementing VVT

- Cam Switching
- Cam Phasing
- Oscillating Cam
- Eccentric Cam Drive
- Three Dimensional Cam Lobe
- Two shaft combined Cam Lobe
- Co-axial Two shaft combined Cam Lobe
- Helical Camshaft
- Camless Engines

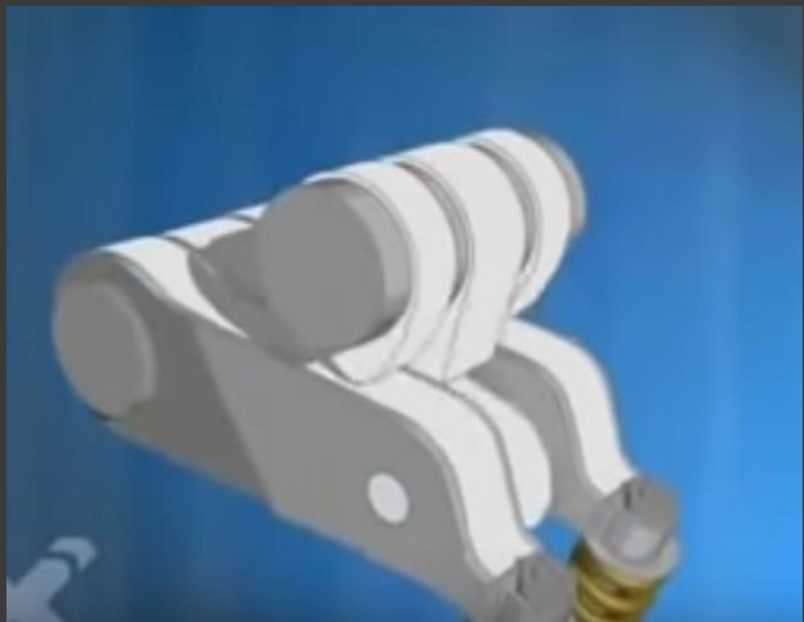
Cam Switching

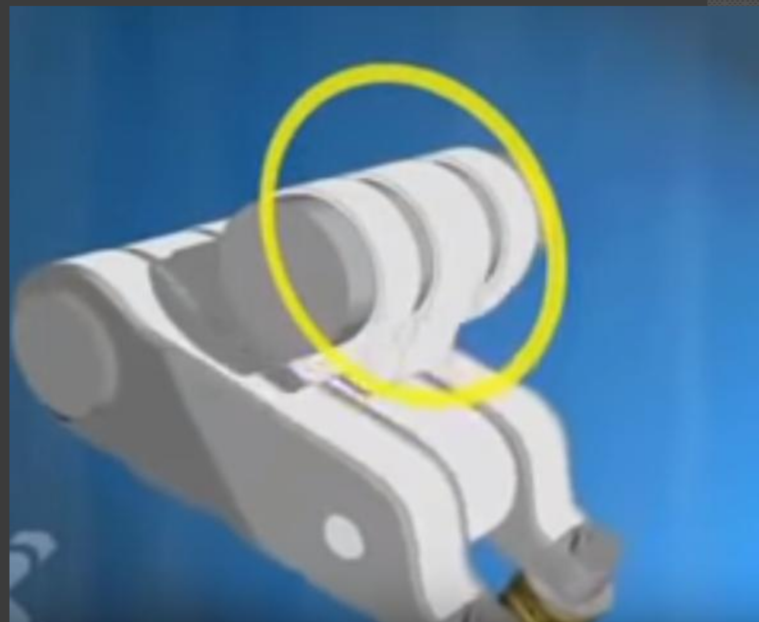
For example:Honda VTEC

- Uses two cam profiles and an actuator to swap between the profiles.
- Provides variable valve lift and duration.
- Discrete control.

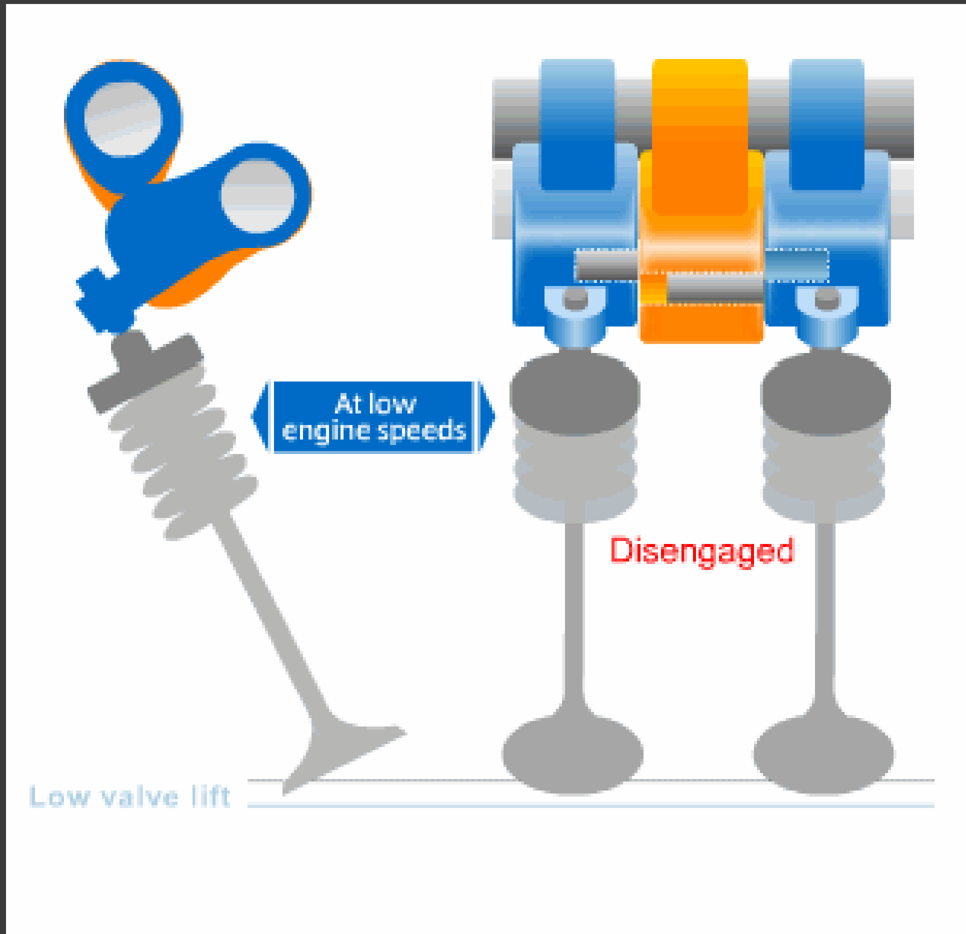
VTEC

- Variable Valve Timing & Lift Electronic Control
- Discrete control.



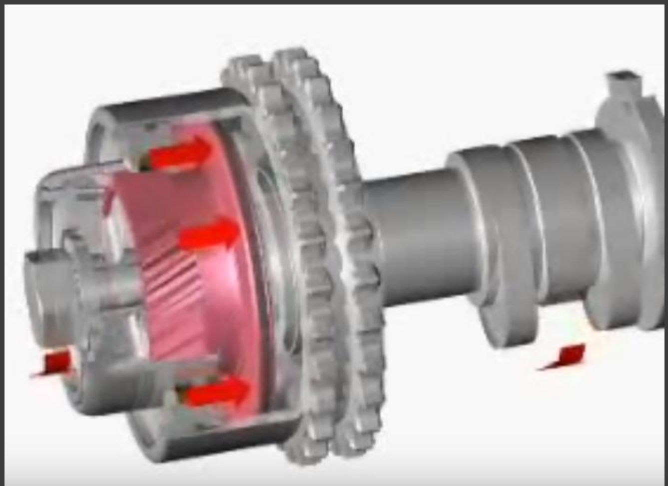


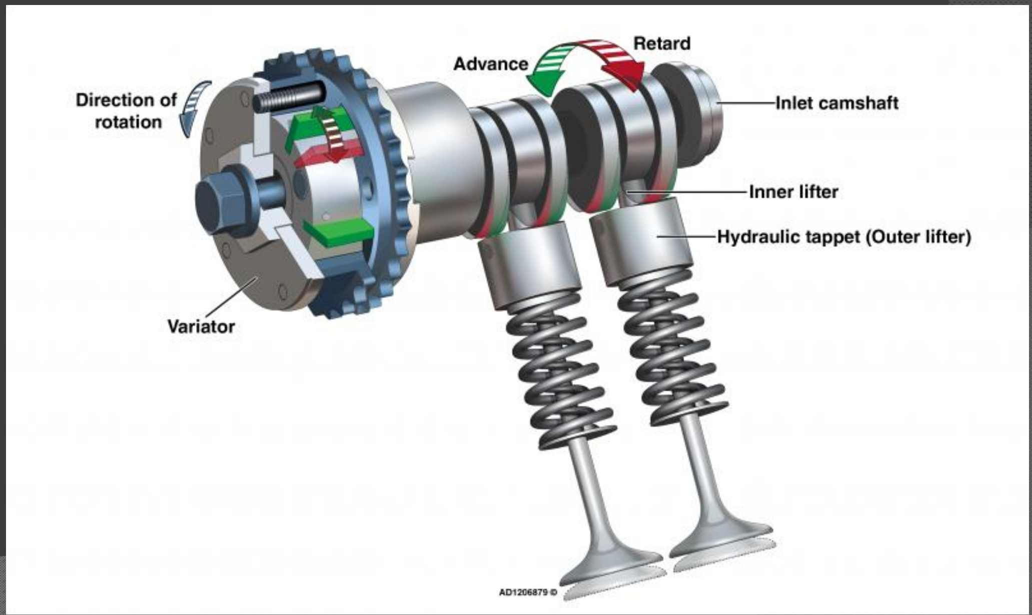
Cam Switching



Cam Phasing

- Phase angle of the cam shaft is changed.
- Provides continuous control.
- Duration and lift cannot be adjusted.



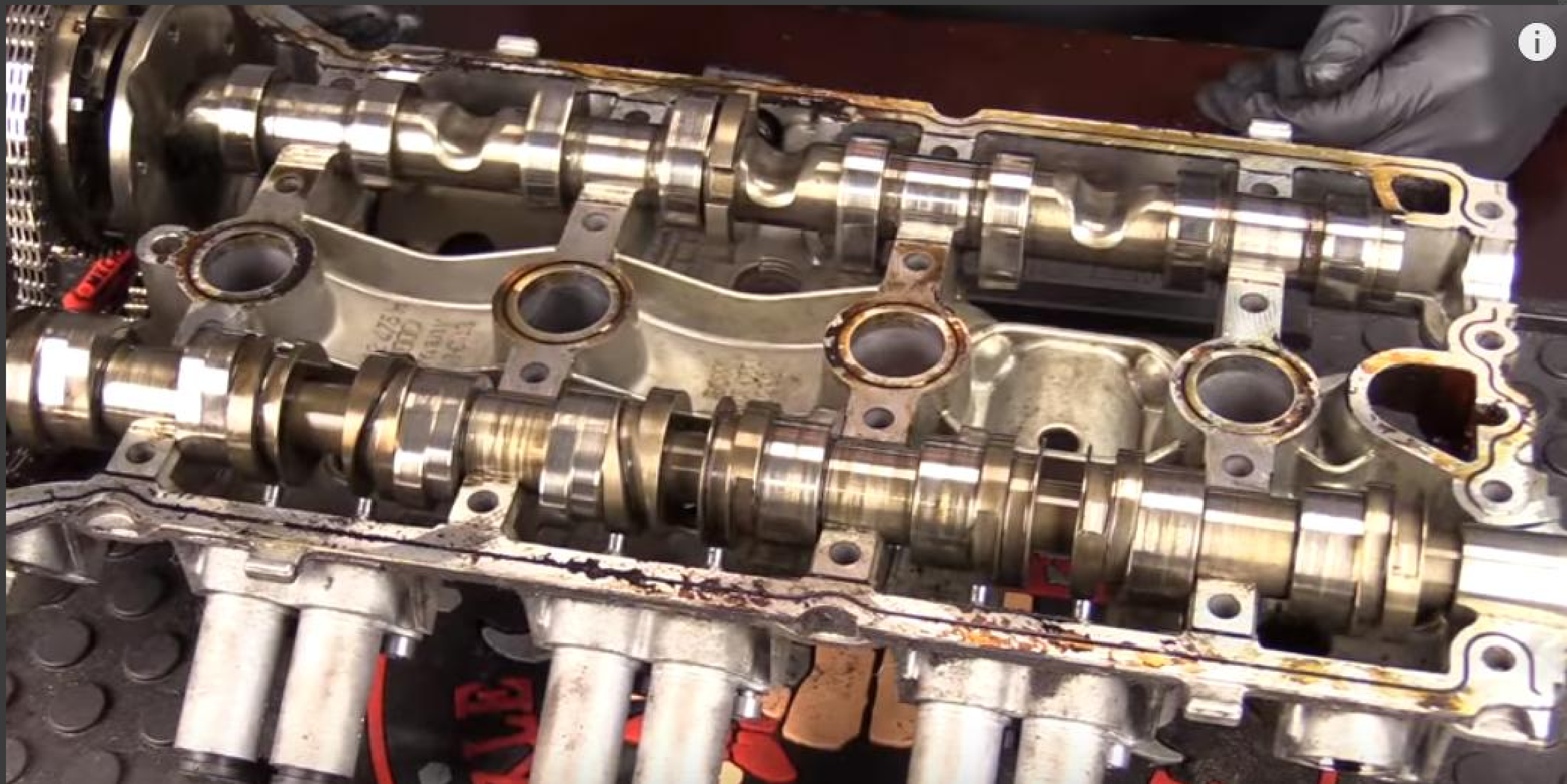


Automotive Nomenclature

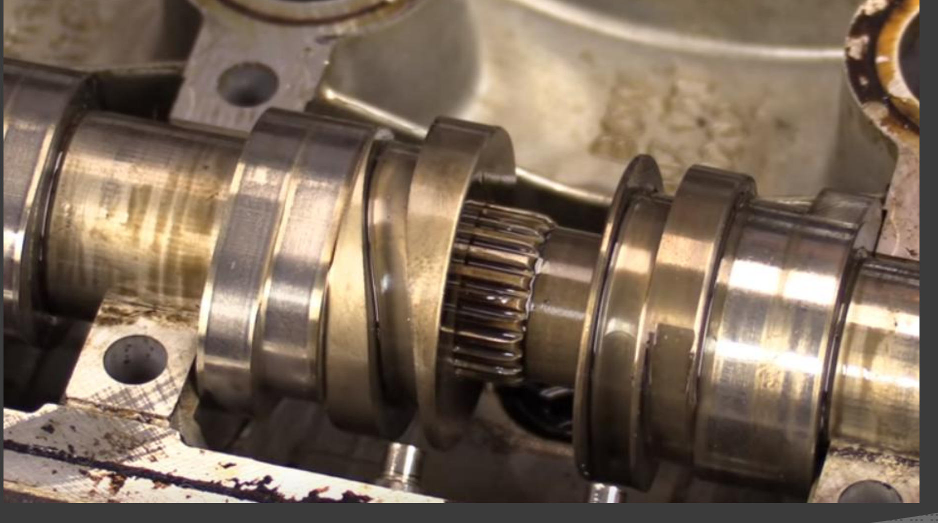
- VarioCam (Porsche)
- VTEC, i-VTEC (Honda)
- Valvelift (Audi)
- AVCS (Subaru)
- VANOS (BMW)

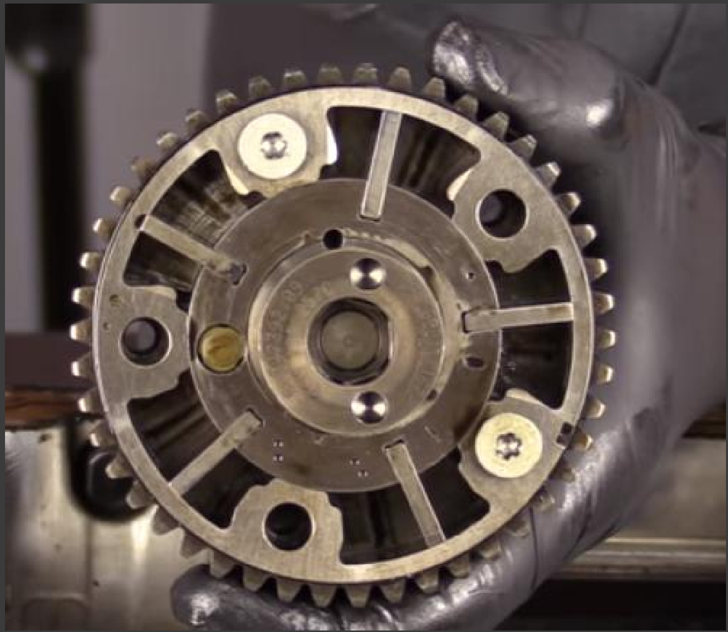
Audi A4 (2009)

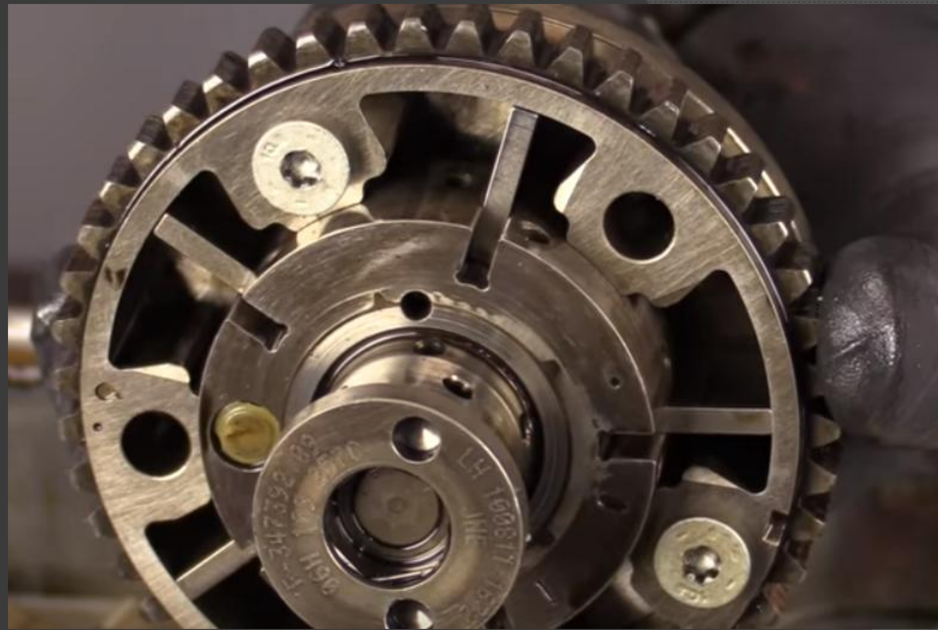
- Exhaust and Intake cam (from below)

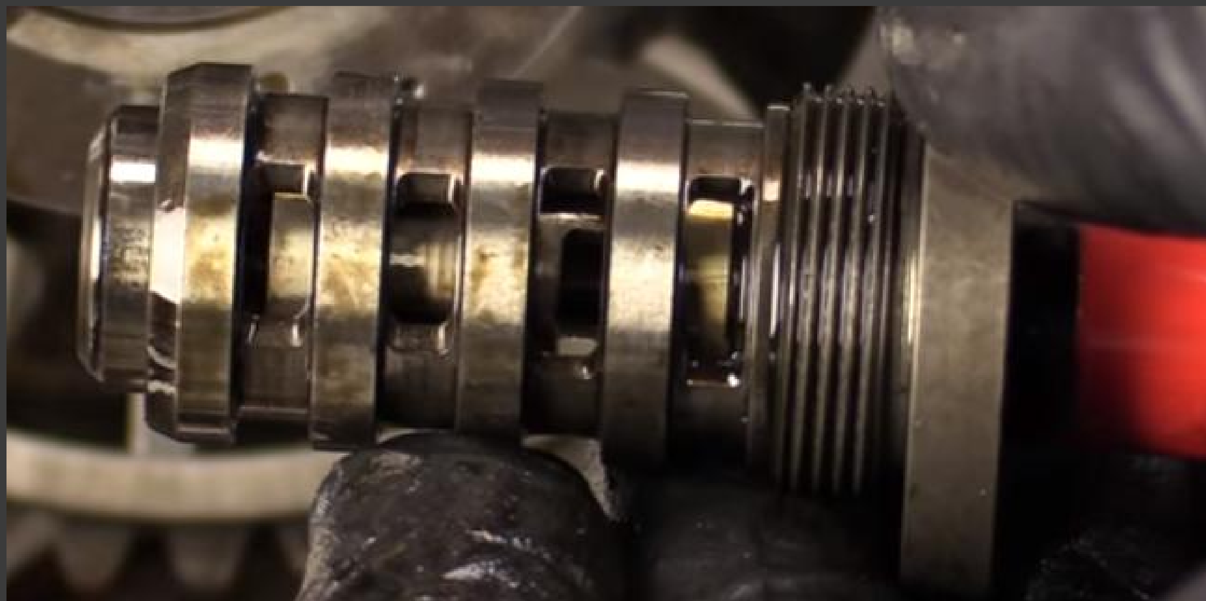



XLB·259

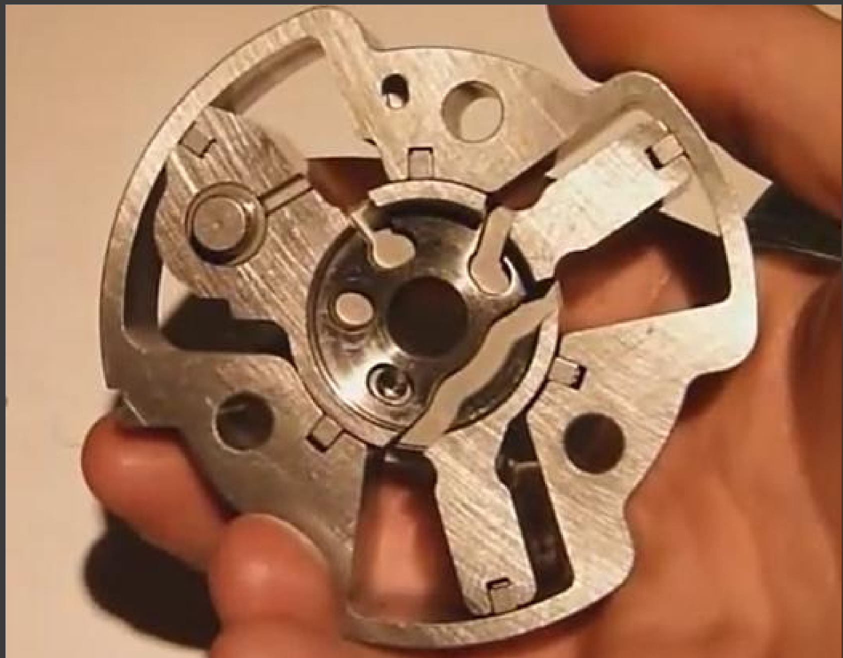




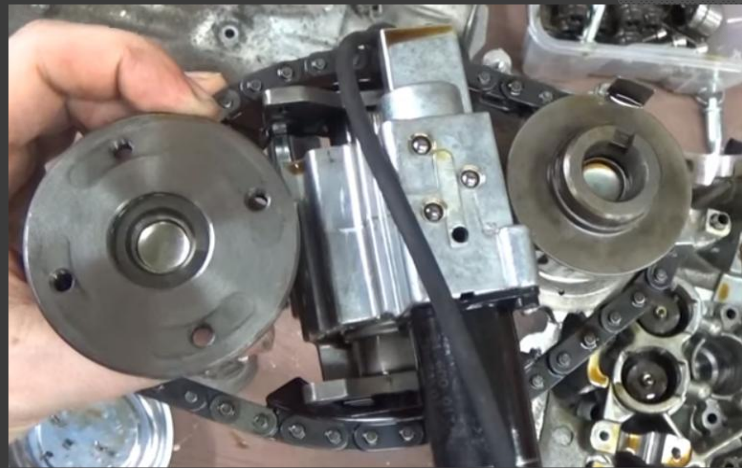


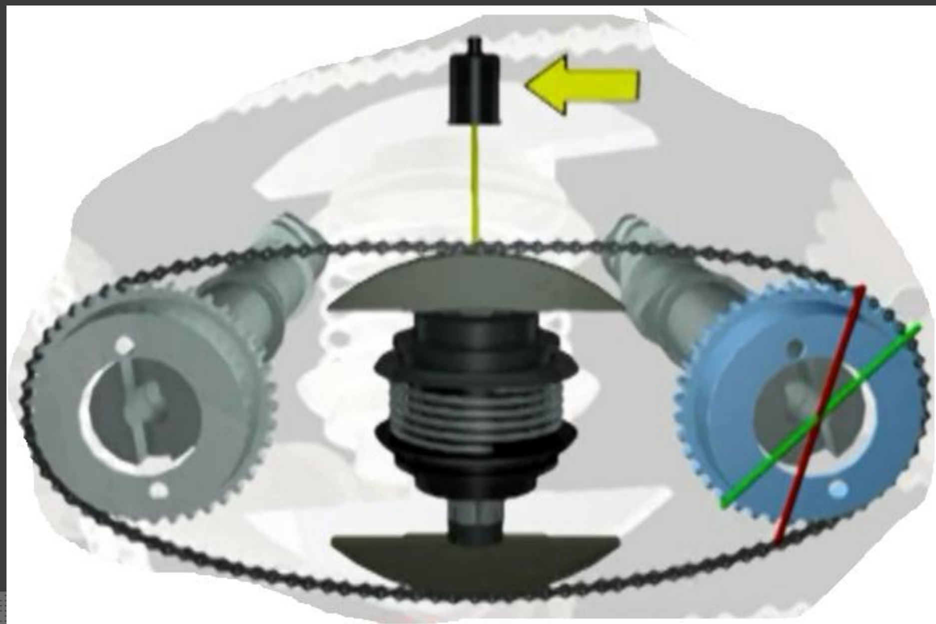


Nissan HR16DE

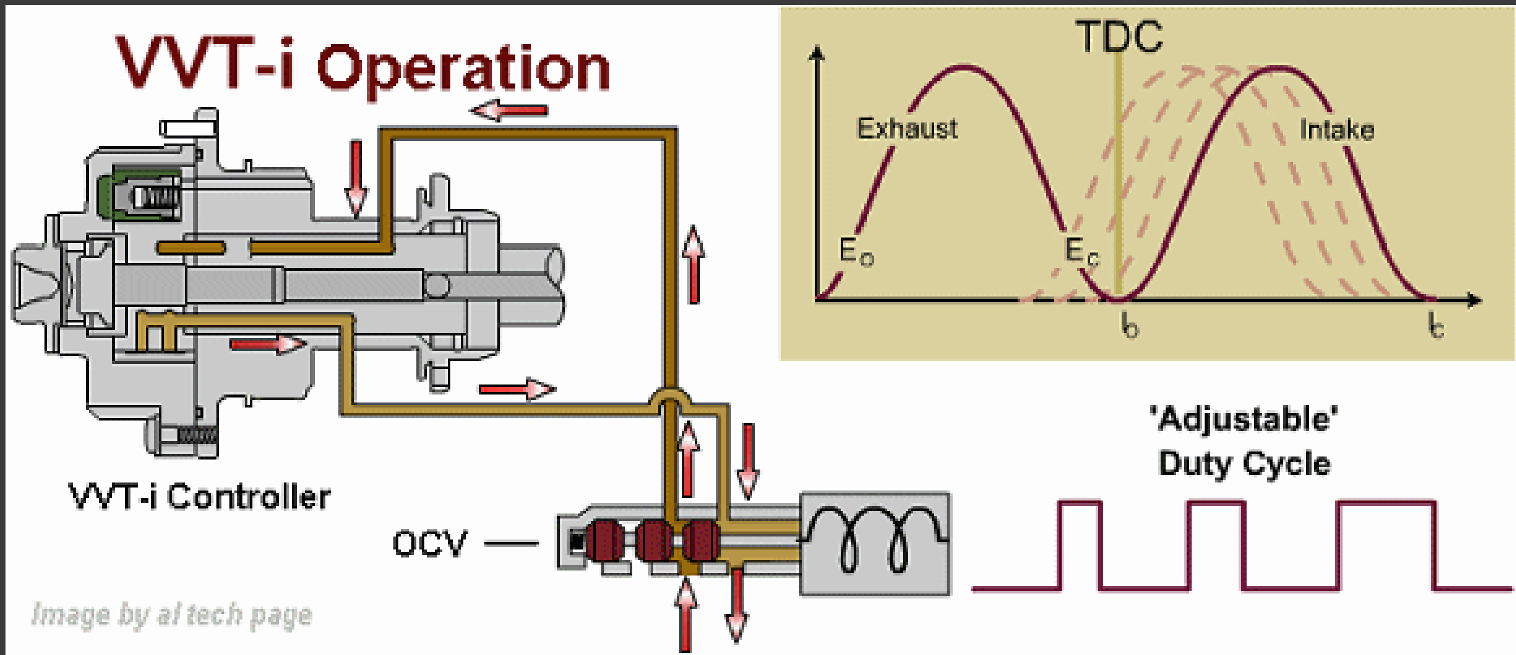


Variocam (Porsche 996 Engine)





VVT-i (Toyota)



VVT-i Operation
VVT-i Controller
OCV
Image by al tech page
TDC
Exhaust
Intake
E_O
E_C
'Adjustable'
Duty Cycle

To Design an Approximate Model

Block Diagram:

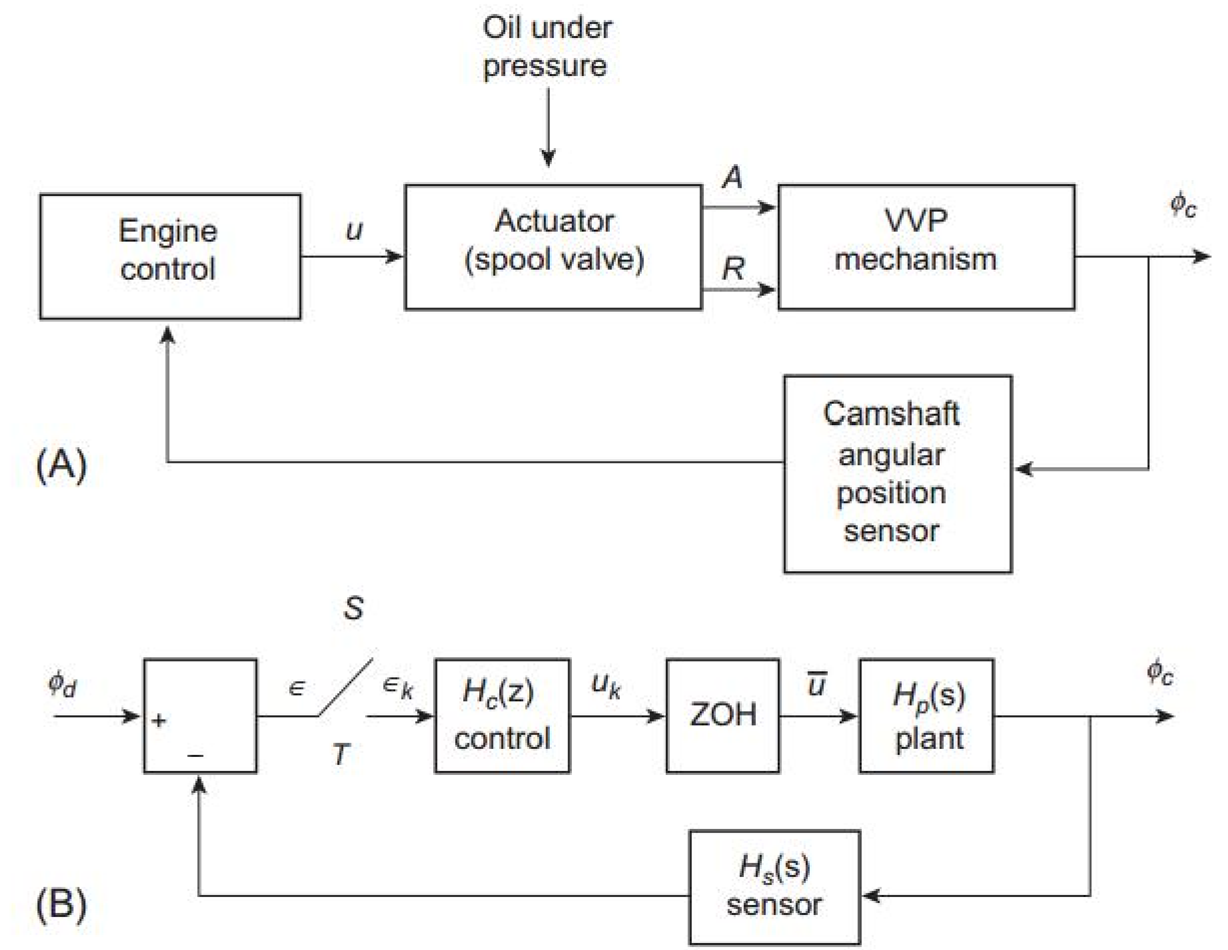


FIG. 6.11 Physical configuration and block diagram of VVP system.

Sensors

- MAP or MAF sensor
- Engine Speed (RPM) sensor (non contact)
- Angular Position sensor (non contact)
  - Hall Effect sensor
  - Magnetic Reluctance sensor

Designing a model:

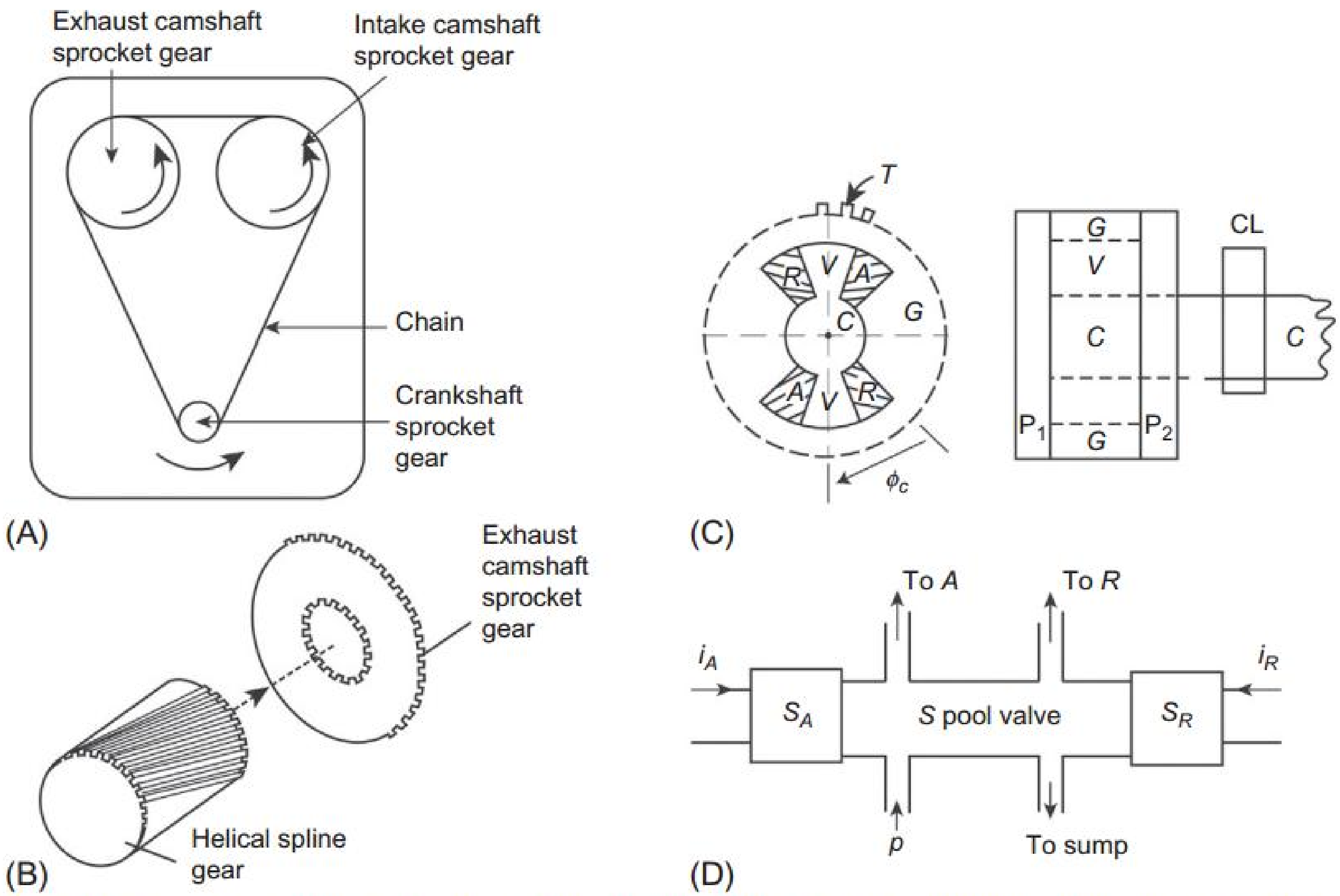
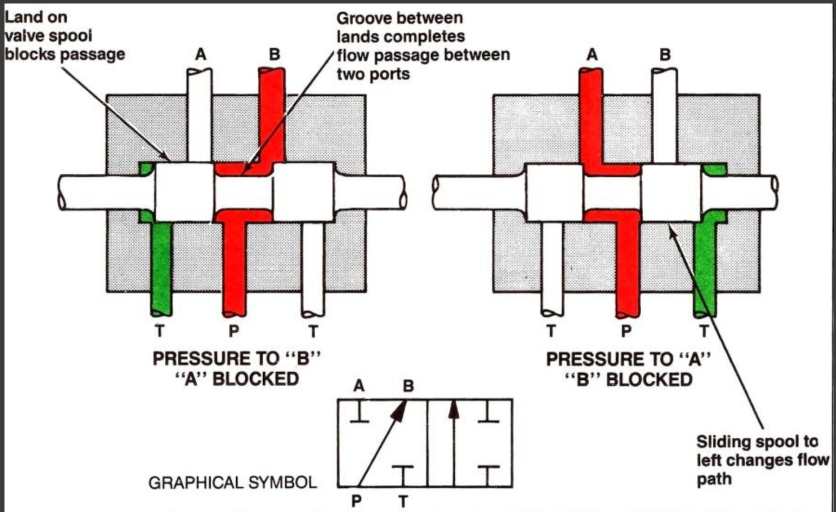
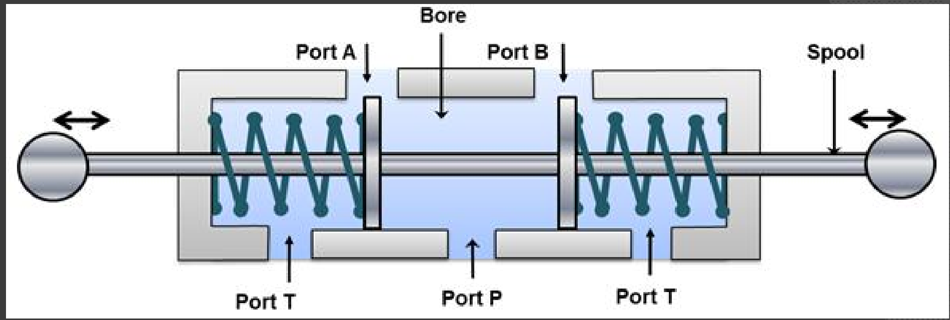


FIG. 5.48 Representative WP mechanisms. (A) Camshaft/crackshaft coupling; (B) Spline VVP adjustment; (C) Differential pressure VVP configuration; (D) VVP control valve.

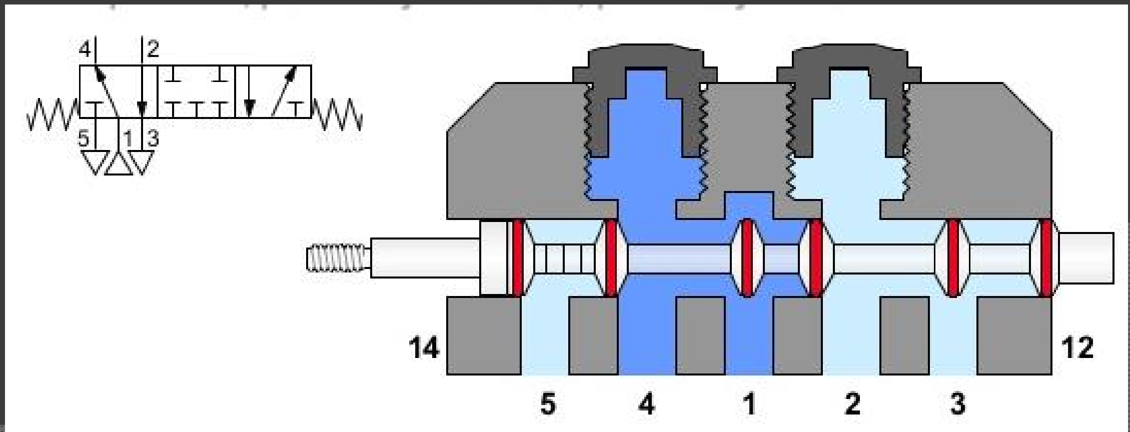
Spool Valve



Land on valve spool blocks passage
Groove between lands completes flow passage between two ports
A
B
T
P
T
PRESSURE TO "B" "A" BLOCKED
A
B
T
P
T
PRESSURE TO "A" "B" BLOCKED
GRAPHICAL SYMBOL
A B
P T
Sliding spool to left changes flow path



Bore
Port A
Port B
Spool
Port T
Port P
Port T



4
2
5
1
3
14
12
5
4
1
2
3

Actuator Design:

- Displacement of the spool valve (x*A*) is proportional to the duty cycle (δ*A*) of the pulsed current (i*A*).
- The pressure in chamber A denoted p*A* (for a given supply pressure from the main oil galley) is proportional to spool valve displacement, which is proportional to δA. The model for chamber A pressure is given by

$$p_A = k_{pA}\delta_A$$

- The torque acting on the camshaft to advance the cam phase Tc is given by where kc is the constant for the geometry and for constant oil supply pressure

$$T_c = k_c\delta_A \quad \text{for } i_A \text{ nonzero}$$

Actuator Design:

- For a linear actuator; u being the electronic signal from the ECU:

$$T_c = k_c u$$

$$\begin{aligned} u &= \delta_A \quad & i_A \text{ nonzero} \\ &= -\delta_R \quad & i_R \text{ nonzero} \end{aligned}$$

- Dynamic motion can be represented as:

$$J_c\ddot{\phi}_c + B_c\dot{\phi}_c = T_c$$
$$= k_c u$$

where J_c = moment of inertia of the components that rotate relative to the gear and B_c = viscous damping coefficient for VVP mechanism.

$$H_p = \frac{\phi_c(s)}{u(s)}$$
$$= \frac{k_a}{s(s+s_o)}$$

$$k_a = \frac{k_c}{J_c}$$

$$s_o = \frac{B_c}{J_c}$$

Block Diagram:

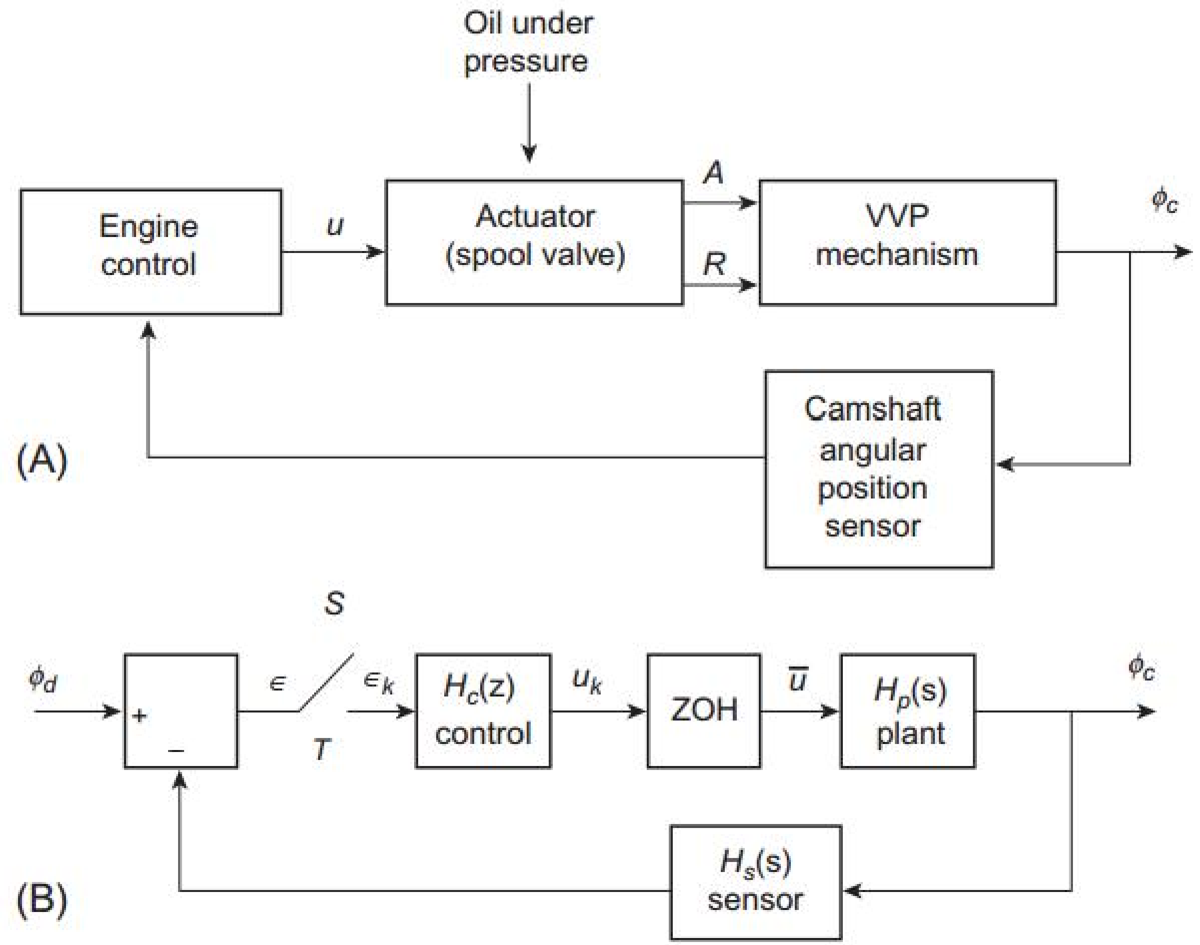


FIG. 6.11 Physical configuration and block diagram of VVP system.

Input Signal:

- Optimal overlap is a function of rpm and load and is decided by engine mapping.
- Desired phasing is stored in the ROM in the ECS for the RPM and load – making the lookup table and used with interpolation.
- RPM Measured using any non contact sensor while load is measured using MAF and RPM or MAP.
- Based on the data, the control unit sends the appropriate signal.
- The actual phase difference is measured by using an angular position sensor on camshaft and its drive gear.

Constraints of VVP

- Should respond quickly to the fluctuating load and RPM conditions.
- Less overshoot and no steady state offset.
- Robust with respect to the oil viscosity (temperature)

- PID Control is used:

$$u = K_p \in + K_D \frac{d\in}{dt} + K_I \int \in dt$$

- After this, time discretisation model is applied to determine u*k* .
- The **zero-order hold** (**ZOH**) is a mathematical model of the practical signal reconstruction done by a conventional digital-to-analog converter (DAC). That is, it describes the effect of converting a discrete-time signal to a continuous-time signal by holding each sample value for one sample interval.
- After the signal processing part, the various parameters are optimised to get the output response.

A typical output response:

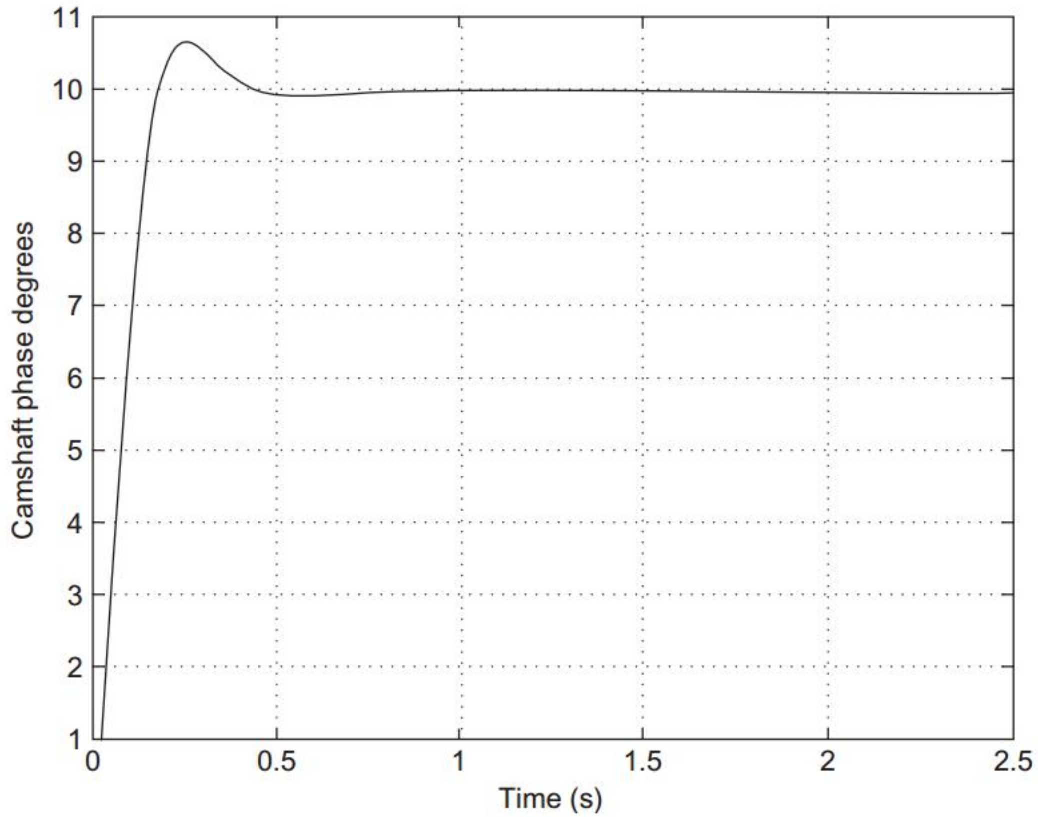
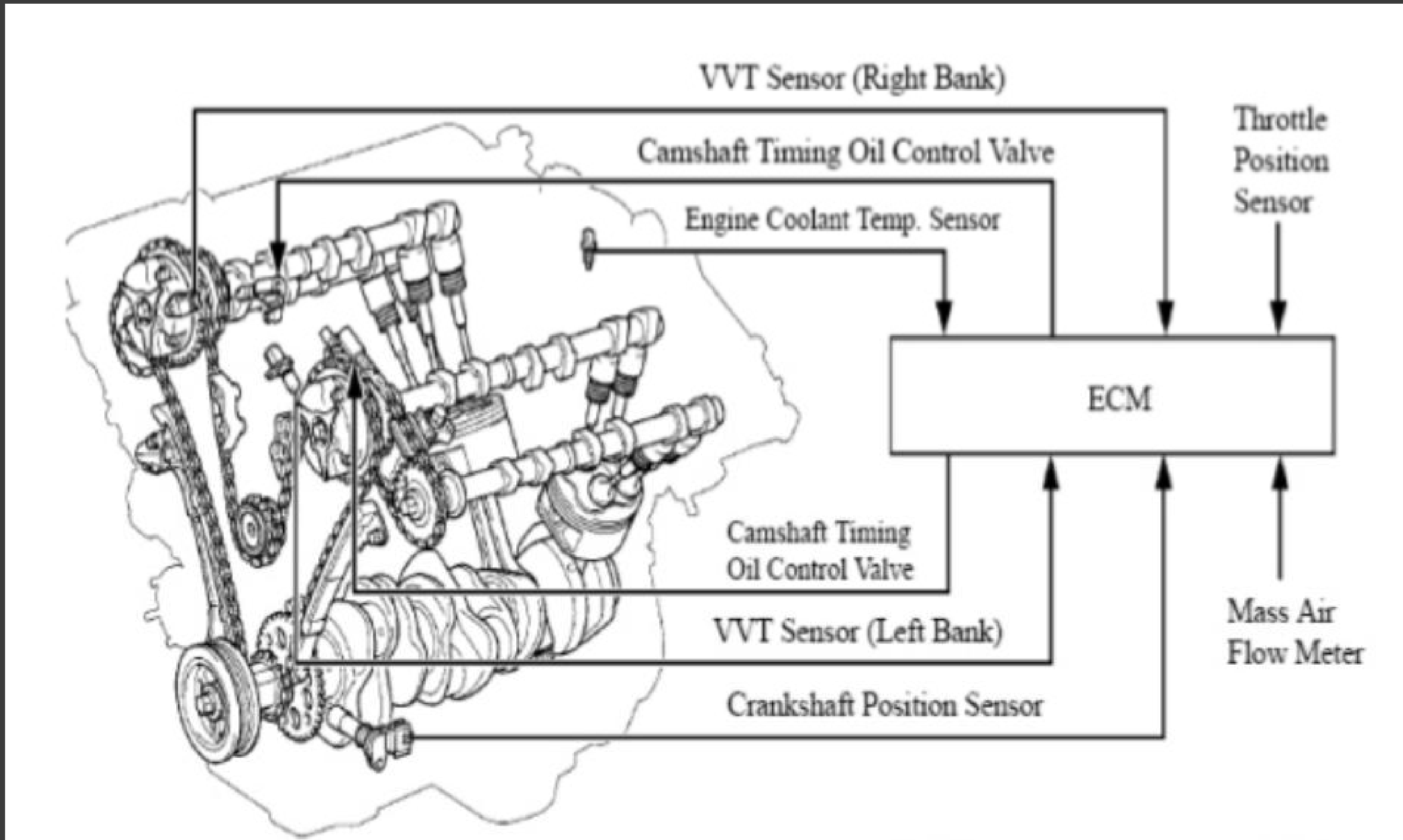
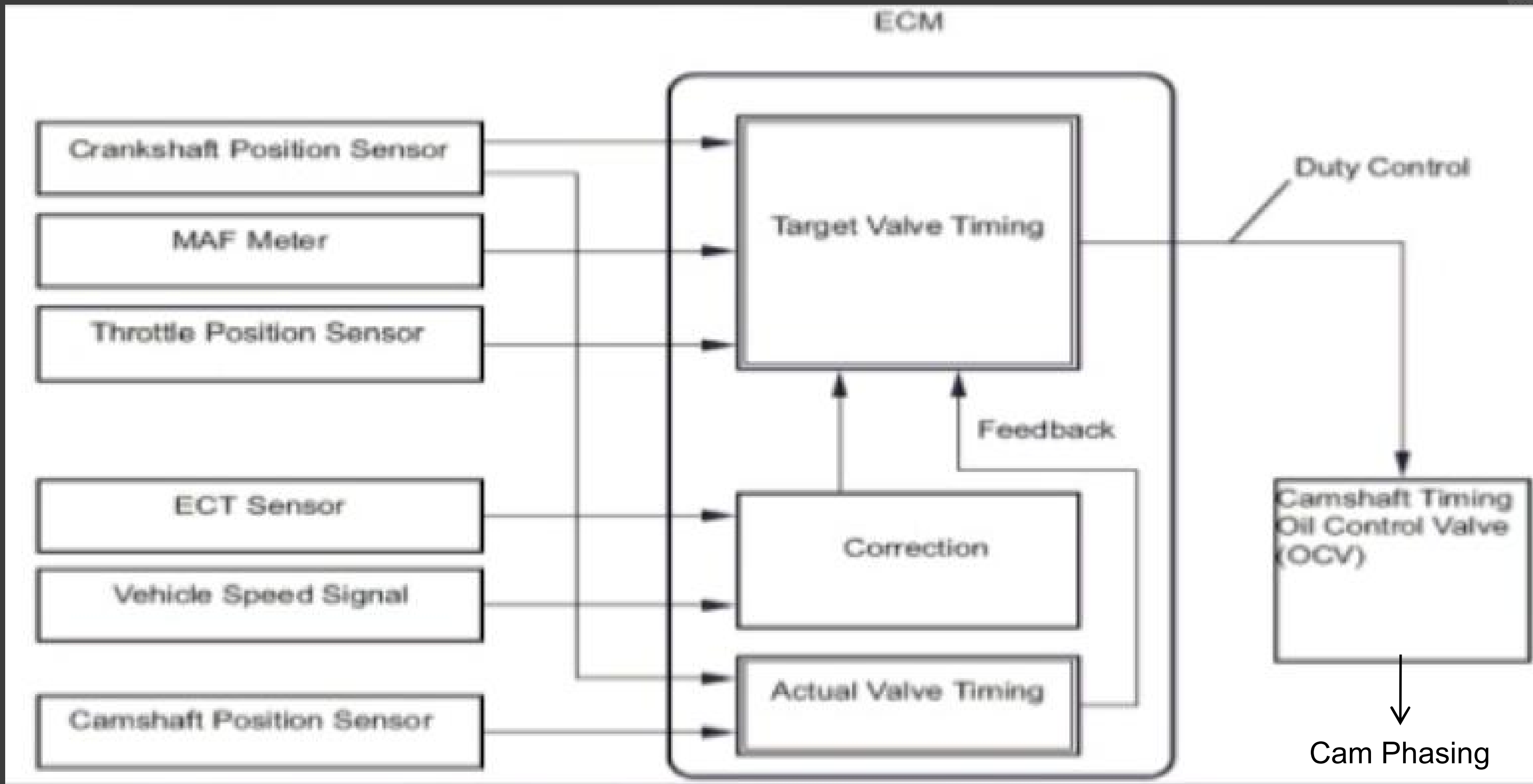


FIG. 6.13 VVP response to 10 degrees step command.

Advanced VVT System:

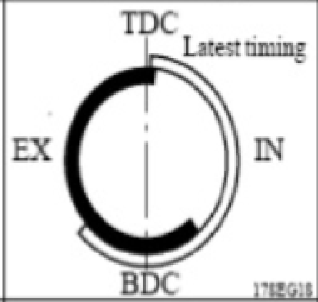
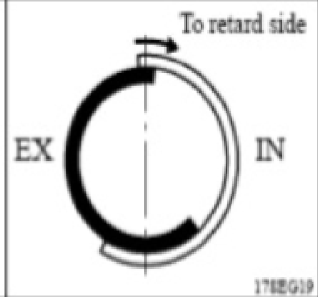
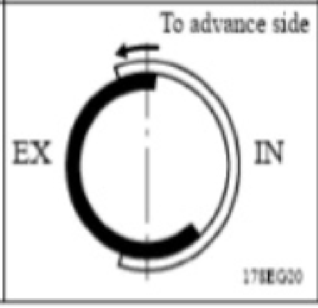


Advanced VVT System:



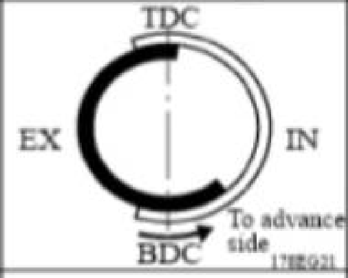
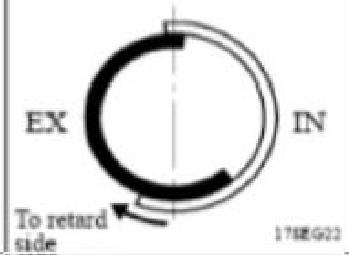
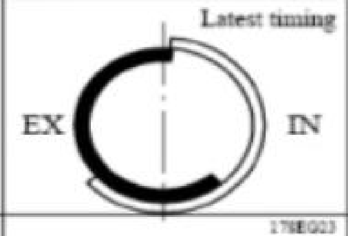
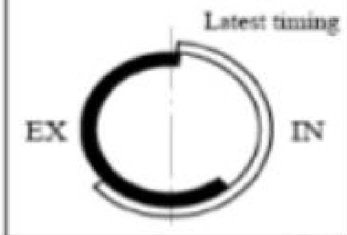
https://www.slideshare.net/souravbagchiprofile/variable-valve-timing?next_slideshow=1

Control Logic:

Operation State	Range	Valve Timing	Objective	Effect
During Idling	1		Minimizing overlap to reduce blow back to the intake side	Stabilized idling rpm Better fuel economy
At Light Load	2		Decreasing overlap to eliminate blow back to the intake side	Ensured engine stability
At Medium load	3		Increasing overlap to increase internal EGR for pumping loss elimination	Better fuel economy Improved emission control

https://www.slideshare.net/souravbagchiprofile/variable-valve-timing?next_slideshow=1

Control Logic:

Operation State	Range	Valve Timing	Objective	Effect
In Low to Medium Speed Range with Heavy Load	4		Advancing the intake valve close timing for volumetric efficiency improvement	Improved torque in low to medium speed range
In High Speed Range with Heavy Load	5		Retarding the intake valve close timing for volumetric efficiency improvement	Improved output
At Low Temperatures	—		Minimizing overlap to prevent blow back to the intake side for reduction of fuel increase at low temperatures, and stabilizing the idling rpm for decreasing fast idle rotation	Stabilized fast idle rpm Better fuel economy
Upon Starting/ Stopping the Engine	—		Minimizing overlap to minimize blow back to the intake side	Improved startability

References:

- https://en.wikipedia.org/wiki/Variable_valve_timing
- www.youtube.com
- https://www.youtube.com/watch?v=I5dy2Vnf95w
- https://www.slideshare.net/souravbagchiprofile/variable-valve-timing?next_slideshow=1
- Understanding Automotive Electronics (8th Edition) by William B. Ribbens

- https://www.youtube.com/watch?v=_7FM3sKqXvk&feature=youtu.be
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- https://www.google.co.in/search?q=spool+valve&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiWjISrw6HaAhVKK48KHcNDCKgQ_AUICigB&biw=1536&bih=710#imgrc=9aorPqsM3UCp2M:
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- https://www.google.co.in/search?hl=en&authuser=0&biw=1536&bih=759&tbm=isch&sa=1&ei=gzfEWpjLLIuV8wWJnbvwAw&q=VTEC+Cam+profiles&oq=VTEC+Cam+profiles&gs_l=psy-ab.3...27155.32285.0.32735.0.0.0.0.0.0.0.0..0.0....0...1c.1.64.psy-ab..0.0.0....0.Tnnt_dVhbJ8#imgrc=iqnAFAfJT5UD4M: