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# A REVIEW STUDY ON VARIABLE VALVE TIMING SYSTEMS

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***ABSTRACT-***
**Variable valve timing(VVT)is the process of alternating Timing of a valve lift event. In internal combustion engines particularly for spark ignition (SI) engines, valve events and their timings have a major influence onthe engine's overall efficiency and its exhaust emissions Because the conventional SIengine has fixed timing and synchronization between the camshaft and crankshaft, a compromise results between engine efficiency, performance and its maximum power. By using variable valve timing (VVT) technology it is possible to control the valve lift, phase, and valve timing at any point on the engine map, with the result of enhancing the overall engine performance.**
**During the last two decades, remarkable developments have been seen in the field of VVT. This paper reviews the literature in the technology of intake and exhaust philosophies of VVT and their effects on the pressure–volume (P.V.) cycle of the engine.**
**Key words: variable valve timing, compression ratio, valve lift event, SI engines, valve overlap**

INTRODUCTION
Amajorgoalofenginemanufacturersistominimizespecificfuelconsumptionandemissionsfromenginesone solution is by the independent actuation oftheinletandexhaustvalvesatanypositionofthepiston,with no more need for acamshaft.
A major disadvantage ofconventional sparkignition(SI)enginesresultsfromtheenergylossesduringtheinhaling of the sub-atmospheric gases duringthesuctionduring the exhaust stroke. These pumpinglossesdependon the opening and closing position of thethrottlevalve.The losses are high when the throttle valve tendstocloseandarelowatwide-openthrottle.Thus,thepumpinglossesareinverselyproportionalwiththeengineload.Withoutathrottlevalve,controloftheair–fuelmixturecanberealizedbyvariationoftheintakevalve-openingperiod; therefore, variable valve timing (VVT) has great potential for reducing pumping losses.

## VALVE EVENTS OF CONVENTIONALSI ENGINES

Intake valve opening (IVO)-
The inlet valveopens and air-fuel charge is sucked into the cylinder as the piston moves downward from top dead Centre (TDC). It continues until the piston reaches its bottom dead Centre (BDC). Generally, opening of the intake valve takes place at around 10 degrees before TDC during the exhaust stroke.Opening of the inletvalve represents the start of the intake stroke As well as the start of intake and exhaust valve overlap.
Exhaust valve closing (EVC)-
The exhaustvalve closes when most of the burned gases have been expelled to the exhaust manifold
This is the end of the exhaust stroke as well as the end of valve overlap. Closing of the exhaust valve take place around 10 degrees after TDC during the intake stroke.
Intake valve closing (IVC)-
Closing of theinlet valverepresents the end of the intake stroke and the start ofthe compression stroke the inlet valve closes at around 50 degrees after BDC during the compressionstroke.
Exhaust valve opening (EVO)-
Opening of the exhaustvalve represents the end of
the expansion stroke and thestart of theexhaust stroke. The exhaust valve openingtakes place at around 60 degrees before BDC.
Intheabovediscussiontheanglesofopeningandclosing of the inlet and exhaust valves are takenasbaseline angles representative of any conventionalcam-operated SI engine (seeFig.1).

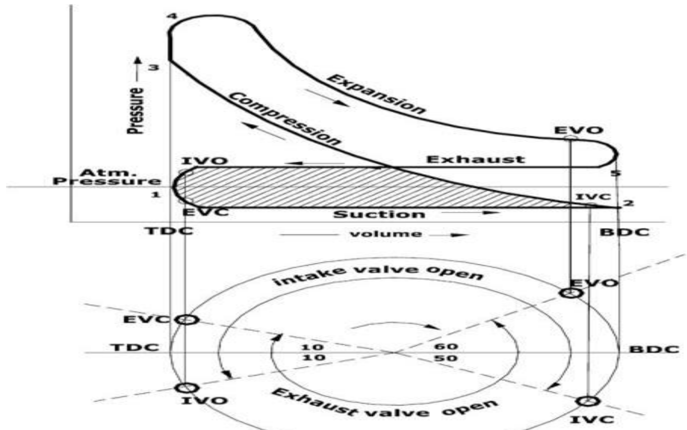


**Fig. 1** Valve timing diagram in relation with PV diagram for conventional four-stroke engine.

## VARIOUS INTAKE AND EXHAUST PHILOSOPHIES

The main characteristic of conventional cam-operated engines is that the intake valve always performs the same displacement at a well-defined crankshaft angle and is independent of the engine working conditions. Variable valve actuation (VVA) can enable the varying of valve events as per engine speed and load requirements.
Among the various intake and exhaust philosophies are:
1. Late intake valve closing (LIVC).
2. Early intake valve closing (EIVC).
3. Late intake valve opening (LIVO).
4. Early intake valve opening (EIVO).
5. Early exhaust valve opening (EEVO).
6. Late exhaust valve opening (LEVO).
7. Early exhaust valve closing (EEVC).
8. Late exhaust valve closing (LEVC).
Combinations of some of the above philosophies are also

possible. In this paper, the above-mentioned philosophies are discussed.

Idealized pressure–volume (PV) diagrams of various intake and exhaust situation for 4-stroke SI engines are discussed in paper. Note that the negative loops (pumping losses) have been exaggerated for illustrative purposes. Any effects on the positive loop are not considered.

**1.Late intake valve closing (LIVC)**

In the LIVC system, the closing of the intake valve isdelayed towards the end of the compression stroke. Ina conventional engine, during the induction stroke theintake valve opens and the charge is admitted into thecombustion chamber. During the compression strokethe intake valve closes and the charge gets compressed.But particularly in LIVC, the inlet valve remains open fora little longer during part of the compression stroke, sothat some of the charge is expelled back into the intakemanifold. The pressure of the entrapped charge is littlemore than atmospheric pressure. During the subsequentinduction stroke the entrapped charge gets readmittedat a pressure above that of the air–fuel mixture in conventionalengines. This means that the suction pressureline deviates very little from the atmospheric line. Thus,the negative area is reduced, which results in reducedpumping losses, as shown in Fig. 2. In other words, thevacuum created in a LIVC engine during suction of theair–fuel mixture is not too low, which results in less force(work) required to complete the induction stroke.

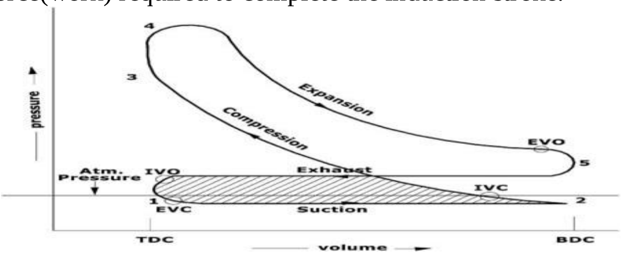


**Fig. 2** PV diagram for LIVC

**2. Early intake valve closing (EIVC)**

The EIVC system is based on closing the intake valves when the desired fresh air–fuel mixture has been introduced. In this way, when low-load and low-speed conditions are required, only a desired and limited fraction of the intake stroke is used to introduce the mixture from the manifold. Then the valve is closed and, in the remaining intake stroke, the cylinder is isolated. This partial intake stroke is the result of early intake valve closing, which reduces the amount of air–fuel mixture admitted inside the engine cylinder. The work (or pumping losses) required for admitting this limited amount of air–fuel mixture is less with respect to conventional engines.

EIVC also results in some pumping losses due to the low lift of the valves. This drawback can be improved by using variable-valve mechanisms that enable faster valve lifts.

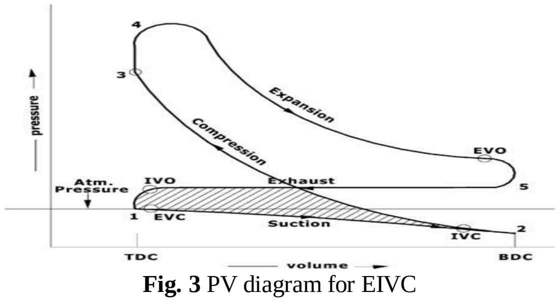


**Fig. 3** PV diagram for EIVC

If the LIVC strategy is compared with EIVC, then in the case of LIVC the manifold pressure is high because part of the air–fuel mixture from the cylinder goes back into the intake manifold. For the EIVC strategy, the manifold pressure is also high but is caused by the restriction of the closing intake valve (i.e. pressure build up due to stopping of the inertia flow). Higher manifold pressure results in more fuel droplets being admitted into the cylinder. More droplets, which are not vaporized, cause poor combustion. EIVC engines can overcome this penalty because of their higher intake air–fuel mixture velocity during the intake phase. This higher velocity creates turbulence for good fuel vaporization. The flow losses for LIVC engines tend to be higher when compared to EIVC because of the air–fuel mixture reverse flow.

**3. Late intake valve open (LIVO)**

Opening of the intake valve is the beginning of the induction stroke as well as the start of the valve overlap period. Normal opening of the intake valve takes place at around 10 degrees before TDC. Late opening of the intake valve tends to cause no flow connection between the cylinder and the intake manifold unless there is a pressure gradient between them. Further delay in the LIVO actually causes the cylinder pressure to dip momentarily below the intake manifold pressure. The pumping losses will be increased because of the greatly reduced cylinder pressure in the first part of the intake stroke.

As shown in Fig. 4, the suction line of the PV cycle is more negative with respect to a conventional engine cycle. Even though pumping losses increase, there is no detrimental effect on the volumetric efficiency.

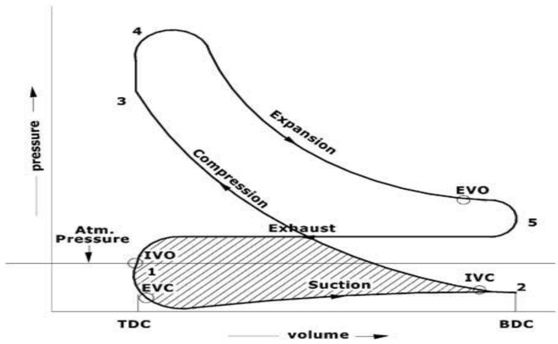


**Fig. 4** PV diagram for LIVO

**4. Early intake valve opening (EIVO)**

In conventional engines, the opening of the intake valve occurs at around 10 degrees before TDC. Early opening well before the end of the exhaust stroke means increasing the duration of the valve overlap. Some of the burnt gases will go back into the intake manifold because of the cylinder-intake manifold pressure gradient. In addition, EIVO allows the exhaust gases to be in contact with the low-pressure intake system for a longer period. Thus, the manifold exhaust gases are recycled back into the cylinder at a lower temperature, which leads to a reduction in NOx.

During EIVO the large intake reverse flow diverts exhaust products temporarily into the intake system, and is later returned into the cylinder along with the new fuel–air mixture. The main cause of reverse flow is due to the pressure gradient between the cylinder and intake manifold. Because some of the exhaust gases go into the intake manifold, this means less burnt gases are being expelled during the exhaust stroke. Thus, the pumping losses are reduced, as shown in the reduction of the negative loop in the PV cycle of Fig. 5.

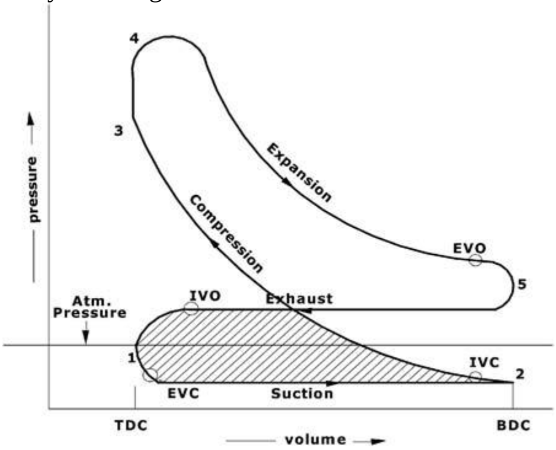


**Fig. 5** PV diagram for EIVO

**5. Early and late exhaust valve closing (EEVC and LEVC)**

The closing of the exhaust valve takes place at around 10 degrees after TDC. It is the end of the exhaust stroke as well as the end of valve overlap.

Closing of the exhaust valve occurs after TDC, which allows the backflow of burnt gases from the exhaust manifold back into the cylinder. During idle, burnt-gas backflow is more dominant because of the high-pressure gradient in the intake manifold and combustion chamber.

Whereas, during part-load and wide-open throttle, the pressure gradient is considerably lower. Also, because of valve overlap, some of the burnt gases may pass into the intake manifold during the exhaust stroke. During the suction stroke these gases will be returned to the cylinder and will add to the trapped-cylinder burnt by products. Also, the exhaust-valve reverse flow that normally follows the exhaust outflow returns burnt gases to the cylinder and thus further increases the residual fraction.

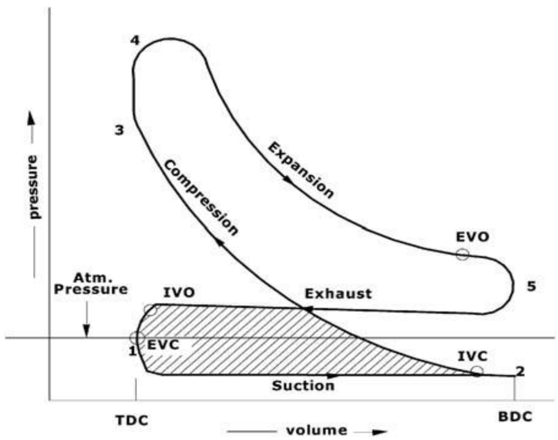


**Fig. 6** PV diagram for EEVC

EEVC may prevent total or partial overlap from occurring. No backflow of exhaust gases can occur from the exhaust manifold to the intake manifold when there is no overlap, but some can occur with partial overlap. The amount of backflow is determined by the amount of valve overlap (see Fig. 6).

For LEVC, the period of valve overlap also increases. During the suction stroke some of the burnt gases from the exhaust manifold flow back into the intake manifold, which thus reduces the quantity of fresh air–fuel mixture (reduces volumetric efficiency). It also reduces the pumping losses during the intake of the new fresh charge because the intake manifold pressure is high, as shown in Fig. 7.

In the case of LEVC, there is more exhaust-gas backflow because of the increase in overlap. A simultaneous but smaller increase in intake-valve reverse flow also occurs, due to the increased valve overlap duration.At high speeds, more valve overlap is beneficial for scavenging of the residual gas, which gives higher power output. But more overlap is detrimental for idle quality due to the larger amount of residual gases going back into the intake manifold. Backflow can be prevented by reducing the overlap, which results in an increase in
torque at idle speed (low speed). But, this will reduce
the volumetric efficiency at higher speeds.

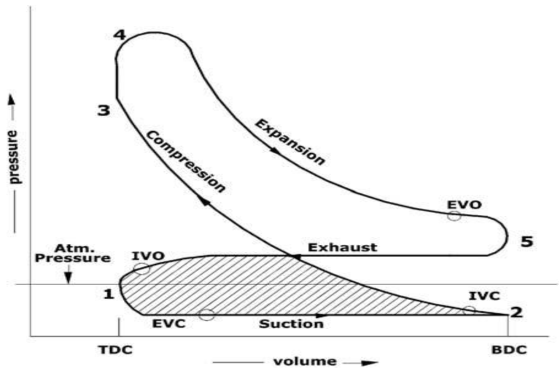


**Fig. 7** PV diagram for LEVC

In the case of LEVC, an amount of the unburned and burned gas mixture is retrieved from the exhaust manifold during valve overlap. This retrieved mixture once again goes through the combustion process with the combustion of the new air–fuel mixture, which results in the reduction of unburned gases. But still, according to Siewert, LEVC is less effective in reducing HC emissions as compared to EEVC.

**6. Early and late exhaust valve opening (EEVO and LEVO)**

EEVO occurs well before the end of the expansion stroke. This early timing provides better scavenging of burned gases, but it causes a reduction in the expansion work (see Fig. 8) and thus reduces the output power of the engine. Therefore, it is detrimental to open the exhaust valve too early. However, there would be a reduction in the pumping work required to evacuate the cylinder after the piston passes through BDC. This is due to the decrease in the mass of exhaust gas during the exhaust stroke. This reduction in mass would require less force to expel them out. In EEVO engines, if the cylinder pressure during the exhaust stroke does not rise appreciably above the exhaust manifold then pumping losses will be minimized.

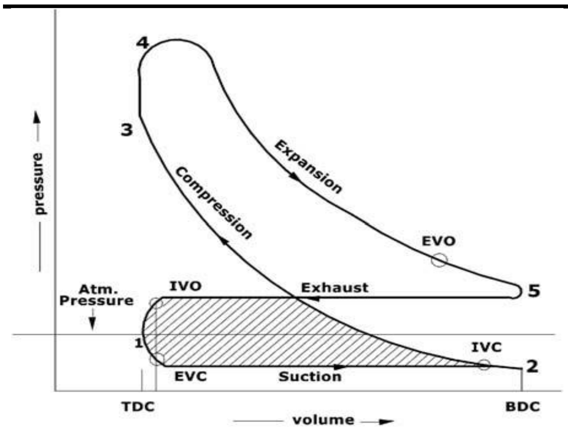


**Fig. 8** PV diagram for EEVO

LEVO reduces the power output because the majority of the work is from the exhaust stroke that is used to expel the burnt gases from the engine cylinder. Thus, a greater pumping loss results (see Fig. 9). Unburned HC are also affected by exhaust-valve opening timing. In case of LEVO, gases get more time to blow-down, which helps good cylinder oxidization.

More exhaust-valve opening delays causes a greater amount of the residual gases to be expelled during the overlap period. Then, there is the possibility of the exhaust gas flowing into the intake manifold during the overlap period.

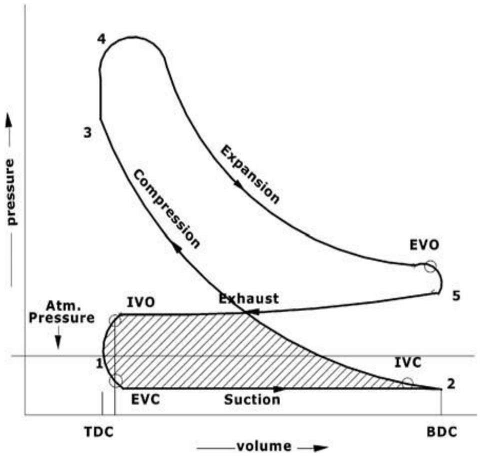


**Fig. 9** PV diagram for LEVO

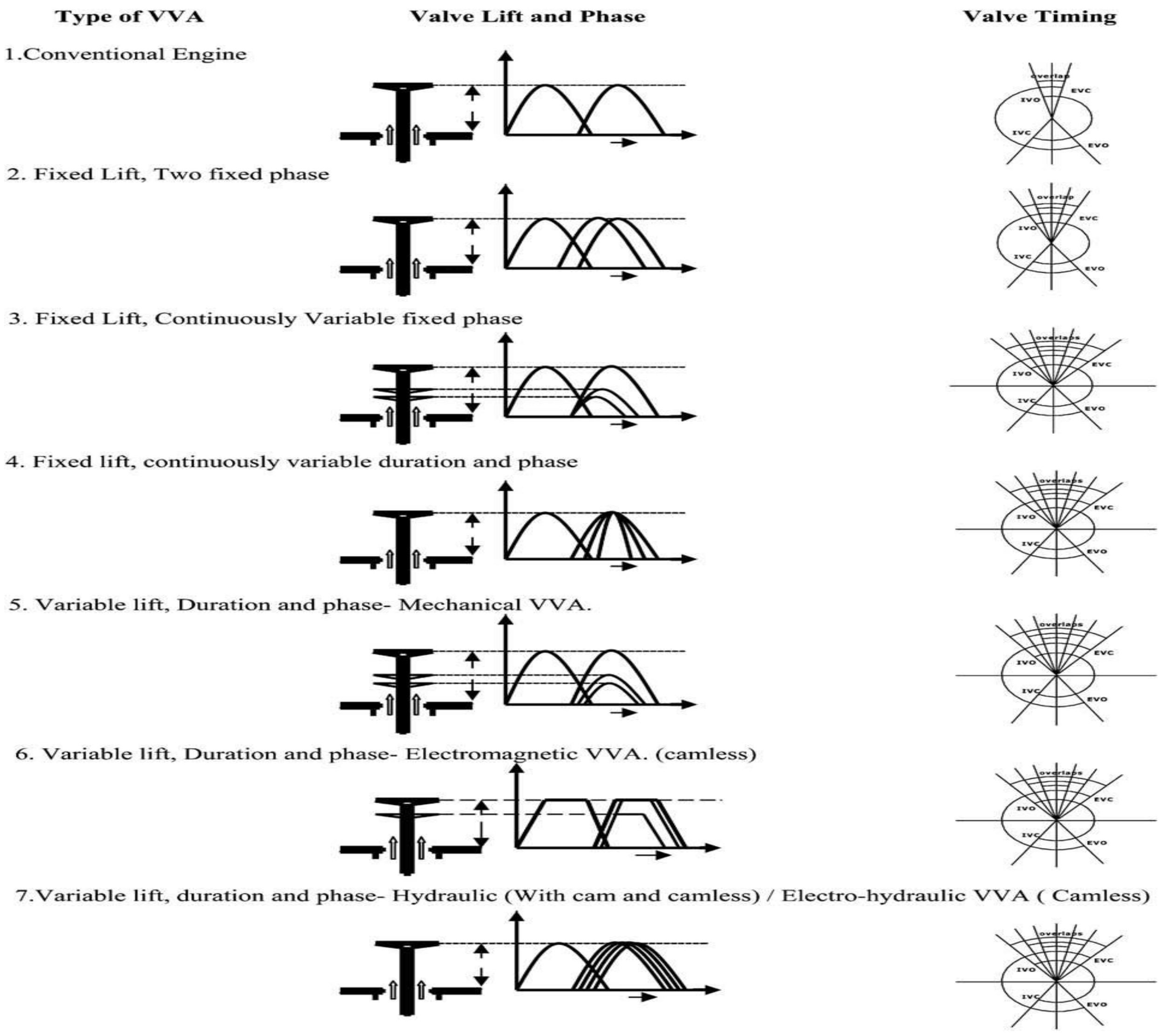


Fig. 10 Valve lift and Valve timing for various VVT mechanism

## CONCLUSIONS

A wide variety of intake and exhaust valve-timing philosophies have been discussed, each having its own advantages and limitations.

PV diagrams for the various philosophies presented the flow losses associated with valve timing and valve lift. This presentation is helpful in identifying the potentials of valve timing. Through the paper review, it has been seen that intake-valve timing is the single most important parameter to measure low-speed volumetric efficiency. The review has shown that LIVC and EIVC are the two philosophies where most research has been done.

Results show that EIVC, LIVC, EIVO and LEVO strategies. This clearly demonstrates that intake-valve have a dominant role in reducing pumping losses. Although exhaust-valve strategies do not help to reduce pimping losses, these techniques are very useful in the reduction of NOx emissions by achieving internal EGR. For reducing exhaust emissions, more work is still required with respect to valve overlap and exhaust philosophies. One of the greatest advantages of VVT is that by the manipulation of valve timing it is possible to get internal EGR, which has the potential to reduce NOx
emission. By combining intake and exhaust-valve strategies it is possible to reduce pumping losses and exhaust emission to enhance the engine efficiency.

VVT is a rich field and much research has been done to recognize its potentials. To get the full benefits from VVT, two important aspects are necessary. One is the manufacturing of cost-effective, less complex and reliable valve-timing mechanisms. The second is to understand the benefits from the manipulation of valve timing and its effects on the PV cycle of an engine. With proper VVA mechanism design and control, it can be expected that the PV cycle of any VVT engine can achieve near-zero pumping losses, maximum volumetric efficiency and the minimization of exhaust pollutions.

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