

## DOES VARIABLE VALVE TIMING SYSTEM INFLUENCE THE INTERNAL COMBUSTION ENGINE'S PERFORMANCES?

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**KEYWORDS** – Variable Valve Timing systems, internal combustion engine, volumetric efficiency, engine load, emissions.

**ABSTRACT** – In the beginning of the article it will be presented a short introduction about the necessity of designing and developing newer solutions of VVT (Variable Valve Timing) systems in order to satisfy the actual needs which consist in fuel consumption, exhaust gases emissions and internal combustion engine performances. Further, a comparison between the main VVT systems will be presented so that we could make an idea over cost-performance ratio. After the introduction, the influences that VVT system involve on specific parameters of internal combustion engine: load control, load composition control, in-cylinder gas motion control. Therefore the conclusions will be presented.

### INTRODUCTION

The European Union has signed few years ago the Kyoto protocol. Thus, the control of greenhouse gas emissions was part of numerous constraints that vehicle manufacturers have to satisfy. The reduction of the engine fuel consumption becomes primary requirement, because of the very fast growing finiteness of the fossil fuels as well as because meeting current and the future emissions legislations [3]. During the last several years, the automobile industry has focused on the development of environmentally friendly vehicles to meet the requirements presented above.

The four stroke engines have widely been applied as power source in transportation and other power generation units. However, with the increasing number of such applications, air pollution caused by exhaust emissions has become of primary significance to its environmental impact. During the past forty years, with the pressure of governmental policies and enormous research activity in this area, the emissions ( $\text{NO}_x$ , CO and HC) levels have been decreased significantly [1] and the performances have been raised to a satisfactory level.

The encouraging results that performances have registered are due to the technique of downsizing, to an larger operating range of revolutions per minute and to practical methods used in order to obtain a superior efficiency at both part load and full load of the engine, to realize that the fixed timing of opening and closing the valves, in order to control the gas exchange process, becomes an obstacle.

This is why many automotive companies in the world have rethought their strategies, even from 1980's years, and made the first steps in designing, simulating, testing and using new systems which allow the optimization of gas exchange process. This system is Variable Valve Timing and Lift control. The Variable Valve Timing and Lift Technology provide the possibility to control the valve events, i.e. timing lift and duration (

Figure 1). Various studies have shown that the engine which uses variable valve timing allows the reduction of pumping loss, control of internal residual gas recirculation and emissions, along with improvement of performance over a wide range of revolutions per

minute. All of these factors contribute to a considerable potential improvement in fuel economy [5].

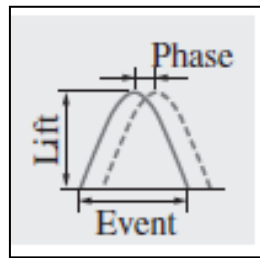


Figure 1 Definition of Variable Valve Timing (Adopted from [4])

		○: Possible    △: Partially possible    ×: Not possible								
Type	Valve lift characteristics	Phase	Lift	Event	Deactivation	Continuous control	Engine performance	Installation	Cost	
With cam	Valve timing control (VTC)		○	×	×	×	○	Low	Good	Low
	Cam switching (VVL)		△→ ○*	○	○	○	×→ △*	↑	↑	↑
	Variable valve event and lift control (VEL)		△→ ○*	○	○	○	○	↓	↓	↓
Without cam	Hydraulic or electromagnetic drive		○	○	○	○	○	High	Poor	High

\* Additional functions made possible by combining with valve timing control.

Figure 2 Comparison of types and functions of Variable Valve Actuation (Adapted from [4])  
Analyzing the

Figure 1 it can be observed that there are three main ways to develop the Variable Valve Timing system. By varying the phase the system will be Variable Valve Timing (VVT); by varying the lift the system will be Variable Valve Lift (VVL) and by varying the event the system will be Variable Valve Timing and Event Lift Control. In

Figure 2 a comparison between the valve systems presented above will be exposed. So, if we desire a more performing system we have to pay extra money to produce it.

**FUNCTIONS OF VARIABLE VALVE TIMING SYSTEMS:**

To understand better the VVT systems, a close look over Figure 3 will reveal the parameters of a gas exchange device. In order to understand and evaluate the effect of VVT system over the performance of an internal combustion engine the performance items of an internal combustion engine must defined: torque output, fuel consumption and emissions. Keeping in

mind the parameters, and the defining measures of a classical gas exchange system, the functions of VVT systems will be presented below using the figure 3:

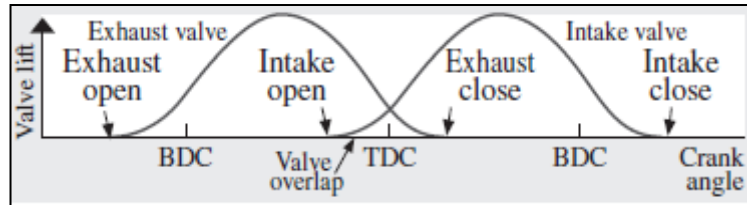


Figure 3 Opening, closing timing and lift of intake and exhaust valves (Adapted from [4])

*Closing the intake valve influence:* valve timing, making variable the intake valve closing many others measures are affected: the throttle-less phenomena, the expansion of the compression ratio, the pumping loss [4].

*Opening the intake valve influence:* valve timing, gas motion, internal EGR, fuel atomization, lower residual gas, pumping loss [4].

*Closing the exhaust valve influence:* valve timing, internal EGR, pumping loss, suppression of fuel adhesion, internal EGR [4].

*Opening of the exhaust valve influence:* valve timing, compression ratio, catalytic converter warm-up [4].

*Valve lift influence:* valve timing, fuel atomization, pumping loss, cylinder deactivation, catalytic converter warm-up [4].

*Valve overlap influence:* valve timing, internal EGR, lower residual gas, pumping loss, suppression of fuel adhesion [4].

*Valve deactivation:* cylinder deactivation or valve deactivation, fuel atomization, low valve lift or deactivation, pumping loss, fuel atomization, gas motion [4].

For a better understanding of the VVT system a close look over p-V diagram must be taken at full load operation and at part load operation

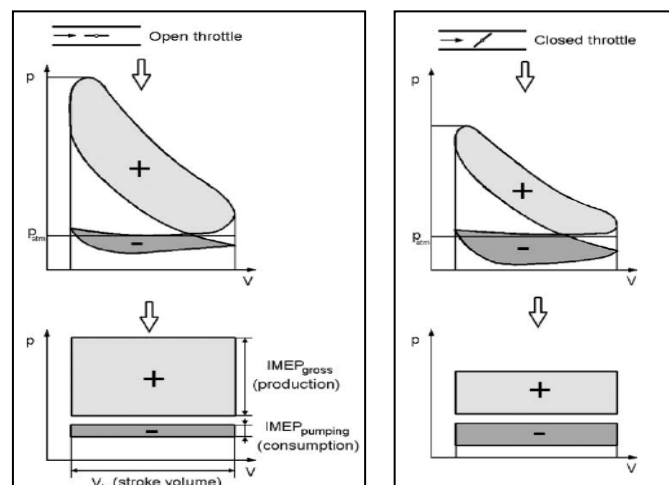


Figure 4 p-V diagram of a four stroke engine at full and part load (Adopted from [1])

It can be observed that at full load the indicated work of compression-boost-detection processes, marked with plus sign, is increased while the indicated work of induction-exhaust processes, marked with minus sign, is negligible. A situation much more complicated is represented by the working conditions of the engine at transient behaviour, at partial loads. In this case the indicated work of compression-boost-detection processes decreases and the work of induction-exhaust processes increases. That means the fact that the level of pumping losses grew up because of the flow restrictions generated by spark ignition throttle, thus the mass of fuel-air inducted decreases.

Regarding the diesel engines the pumping losses appear when in engine's cylinders is inducted a higher quantity of fuel which leads to a bigger thermal level of the engine, thus the fresh mixture is heated in contact with the warm wall of the cylinder which intensifies the thermal losses and the volumetric efficiency is slightly influenced [6].

Beside the aspect of high level of pumping losses at part load, other aspect is necessity of varying the intake valve closing so that the phenomena of backflow and post-filling of the cylinder, with fresh air-fuel mixture, could be optimized [6]. This variation should be dependent on crankshaft's angle.

## INFLUENCES OF VARIABLE VALVE TRAIN SYSTEM OVER INTERNAL COMBUSTION ENGINES PERFORMANCE'S

### ENRICHMENT OF THE GAS EXCHANGE PROCESS USING VVT SYSTEM

The load exchange determines the air mass, the load composition and the in-cylinder gas movement condition of the cylinder load and exercises an essential influence on the targets for: efficiency, exhaust gas emissions, torque/performance, cold start and warm-up behaviour, transient behaviour of the engine [7]. So, using VVT systems these parameters will be optimized.

### LOAD CONTROL USING VVT SYSTEM:

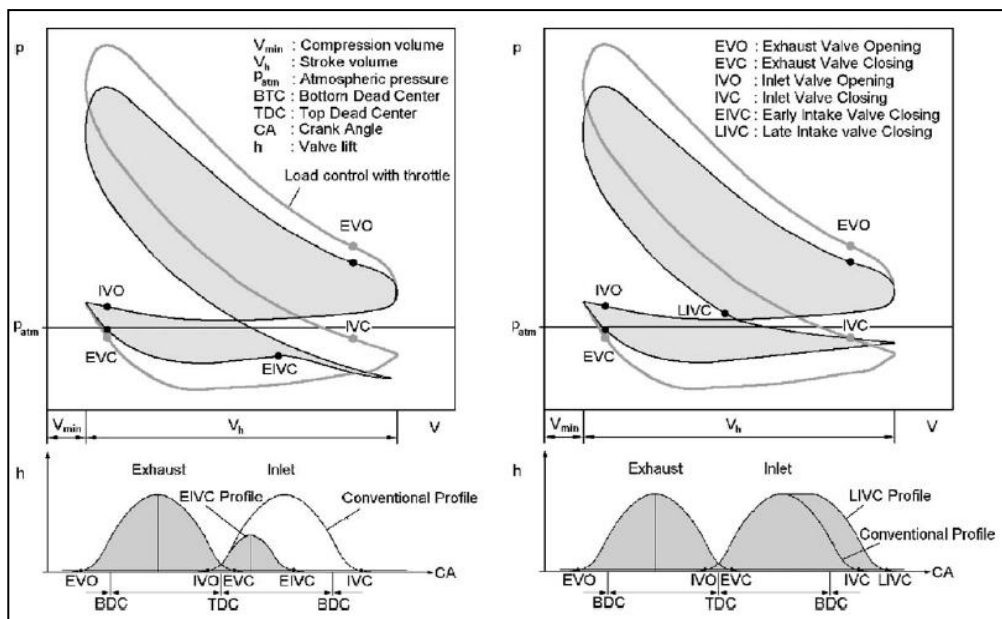


Figure 5 Comparison of load control with and without VVT and lift (early or late intake valve closing) on p-V diagram (Adopted from [1])

The engine load is appreciated by the BMEP (Break Mean Effective Pressure) parameter. The main load control strategies which may be applied are: Early Intake Close (EIC) and Late Intake Close (LIC) [7]. This is how the throttling or pumping losses can be reduced. The engine load is controlled by closing the intake valve early or late without using conventional throttling process of the incoming charge by a throttle plate [1]. As shown in the Figure 5, early or late intake valve closing has a similar effect in reducing (exhaust-intake) loop area, i.e.  $IMEP_{pumping}$  (Indicated Mean Effective Pressure). At the same time, the compression expansion loop area, i.e.  $IMEP_{gross}$ , decreases as compared to the throttle controlled system at equal load conditions ( $IMEP_{net} = IMEP_{gross} - IMEP_{pumping} = \text{constant}$ ), which means that a lesser fuel charge is admitted into the cylinder at equal excess air coefficient ( $\lambda = \text{constant}$ ) [1].

For a HCCI diesel engine the effects of VVT systems are shown in

Figure 6. The red colour contours refer to the results of a typical intake-valve-timing while the black colour plots show the engine parameters corresponding to the non-typical intake-valve-timing strategy. At a constant value of EVC (Exhaust Valve Closing), the engine load increases with the timing of IVO (Intake Valve Opening) up until the optimum point at the symmetric degree of overlapping and then decreases. The symmetric degree of NVO (Negative Valve Overlapping) is represented by the dashed line [8].

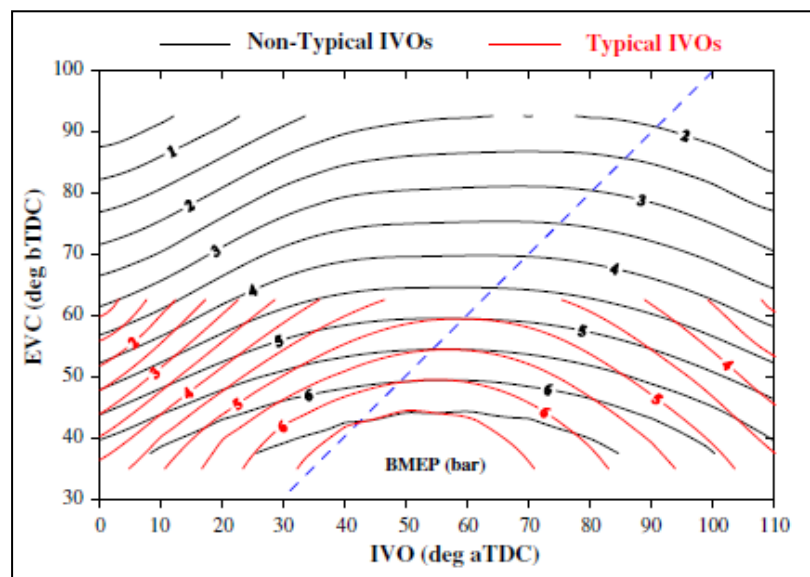


Figure 6 BMEP as a function of IVO and EVC timings (Adopted from [8])

## CONTROL OF LOAD COMPOSITION

It is known that within a cylinder exist three types of gases: the fresh air absorbed during the induction process, the fuel injected or aspired and the residual gases which haven't been evacuated. In the following figures it will be presented the variation of RGF (%) (Residual Gas Fraction), THC (Total Hydrocarbon) and NO<sub>x</sub> as a function of IVO and EVC timings, see Figure 7.

It can be observed that for a constant value of EVC the best RGF percent level is near the symmetrical line of NVO. Using strategies of opening and closing the valves the load composition may be vary.

For early intake valve openings a quantity of fresh and burned mixture is absorbed back into the intake port. Right at the beginning of the next cycle, this mixture with a bigger quantity of fresh air, is inducted again in the cylinder and oxidized. This is how a part of the burned gases are re oxidized. As a result the hydrocarbon emission is diminished with 7.7% [2]. In the same time, the mixture composed of burned and unburned gases influences the temperature of the oxidation process, thus the flame temperature decreases and the NOx genesis is stopped. The results of the IVO different timing are shown in Figure 8.

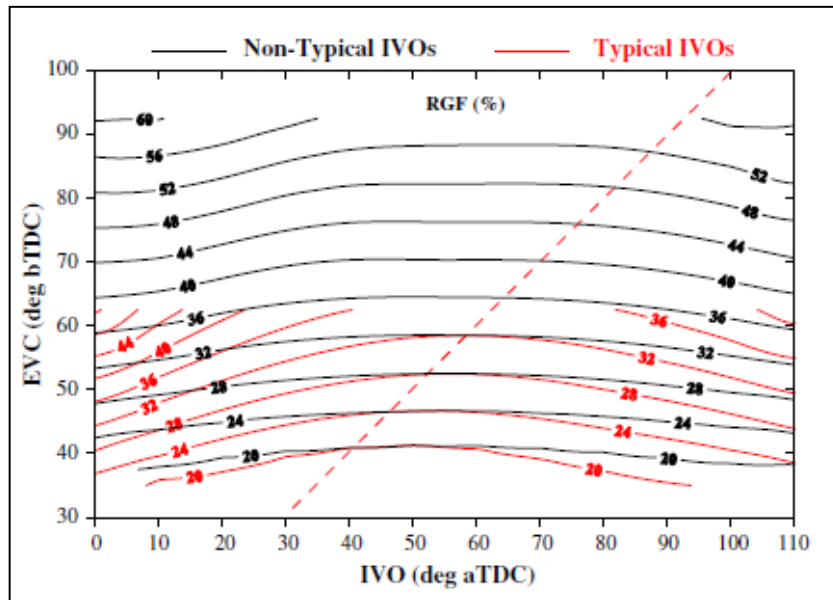


Figure 7 RGF (%) as a function of IVO and EVC timings (Adopted from [8])

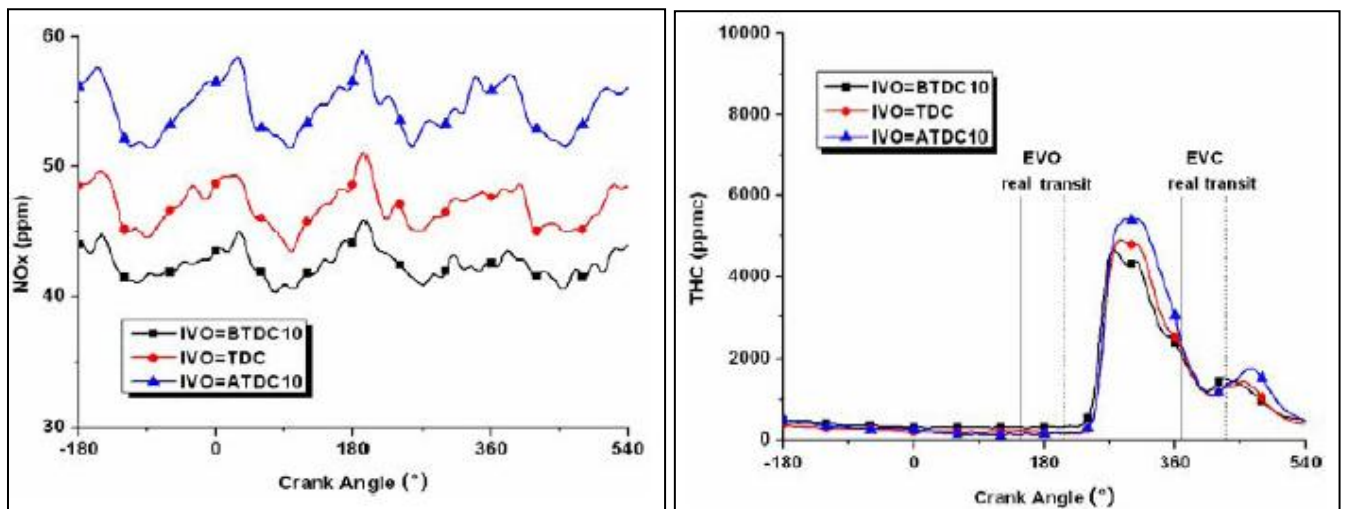


Figure 8, NOx and THC emissions as function of IVO (Adopted from [2])

CONTROL OF IN-CYLINDER GAS MOVEMENT

It is known that the gas circulation within the cylinder may be exist in a general one which consists in three basic movements: swirl, squish and tumble; the swirl motion can be characterized using the formula:

$$SN = \frac{\Gamma}{I \cdot 2 \cdot \pi \cdot rps} \quad [-] \quad \text{adopted from [3]}$$

,  $\Gamma$  and  $I$  are the momentum and

the moment of inertia of in-cylinder charge, respectively.  
*rps* mean revolutions per second.

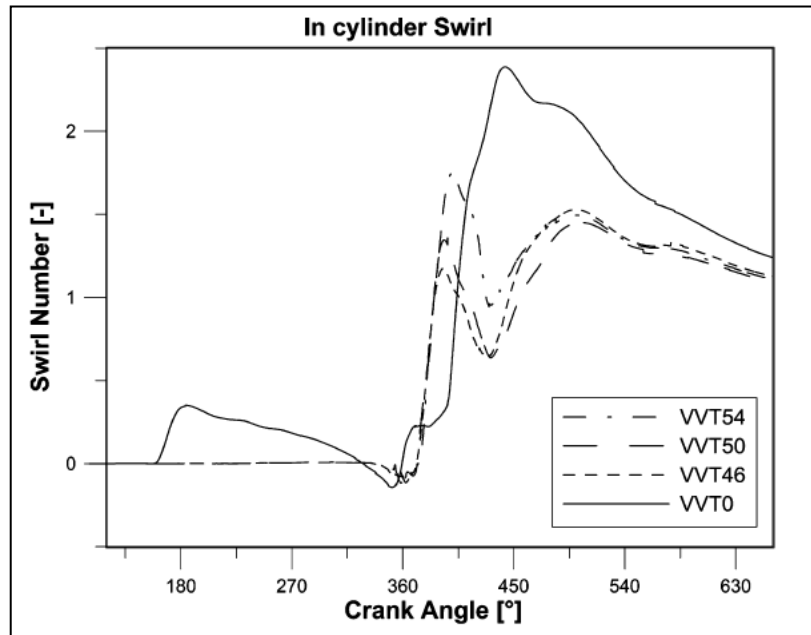


Figure 6 Comparison of the in-cylinder swirl numbers at different cam phaser positions  
 ( Adopted from [3])

It can be observed that using different cam phaser positions the swirl number generated in the cylinder changes, see figure 6. In order to obtain a higher volumetric efficiency and a superior in-cylinder movement of gases, the retarded opening time of the valve must be chosen carefully so that the downwards displacement of the piston creates the depression which induces a large quantity of fuel-air mixture.

If the intake valve opening is too retarded the piston will be close enough to the bottom dead centre point, thus the swirl number will be decreased because of the low speed of the induced mixture, but in the same time a retarded point increases the swirl production during the exhaust reverse flow [3].

## CONCLUSIONS

The VVT&L system can be acquired using three types of mechanisms which are already used on engine's auto vehicles.

Using VVT&L mechanism the pumping losses can be decreased while the volumetric efficiency is raised to a higher level.

VVT&L makes possible the use of HCCI concept on cars by controlling the quantity of inducted and exhausted gases.

VVT&L allows the control of load composition, thus the level of exhaust emission is lowered.

VVT&L controls the in-cylinder gas movement by closing earlier or later the intake valve.

## AKNOWLEDGMENT

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