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THE INFLUENCE OF VARIABLE VALVE TIMING SYSTEM OVER INTERNAL COMBUSTION ENGINE'S PERFORMANCES

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Abstract: *This article presents the influence that variable valve timing system manifests over the internal combustion engine's performance and environmentally parameters. By modifying the moment of opening and closing the valves, earlier or later in comparison with the classical valve timing system, combined with a modified overlap, exhaust gas emission, engine torque, specific fuel consumption and pumping loses are optimized so that the engine become "friendlier" to environment. In the end of the article the conclusion is presented.*

Key words: *internal combustion engine, variable valve timing, emission, process, fuel consumption.*

1. Introduction

The European Union has signed few years ago the Kyoto protocol. Thus, the control of green-house 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. In the last years, because of governmental policies and research activity in internal combustion engine area, the emissions of NO_x, HC and CO levels have been decreased and the performances have been raised to a satisfactory level.

Considering the raised level of exhaust gas emissions and the finiteness of the fossil fuels, very efficient techniques to obtain higher values of engine's performances while decreasing its dimensions were developed by the design engineers. They can be achieved by using solutions like: variable compression ratio, supercharging, cylinder deactivation, variable valve timing and lift, homogeneous charge compression

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ignition combustion, stratified charge lean burn engine.

Regarding emission reduction and increased fuel economy, they may be improved using valve timing techniques combined with fuel control strategy. Hence, there are two main trends which made parameters above to be better, first one is valve timing trend which has next history: cam profile optimisation, camshaft phasing, cam profile switching, mechanical variable valve train, cam-less electro-magnetic valve train, cam-less fully variable valve train [1].

Fuel control trend consist in: developing and using carburettor, electronic carburettor, single point injection, single point injection with multipoint distribution, multi point sequential port injection, direct injection [1].

The two trends and their last hierarchic developed strategies presented above, allow internal combustion engine to be friendlier with environment, consume less fuel and have satisfactory energetically performances.

2. Influences of Variable Valve Timing System over Internal Combustion Engines Performances

It is known that internal combustion engines, both two and four strokes spark ignition or compression ignition, have as functioning principle one of the two basic principles, like: constant volume burning cycle or OTTO/Gasoline engine and the second one is DIESEL cycle or constant pressure burning cycle.

One major disadvantage that the two cycles presented above have is represented by the moment when the exhaust valve opens near the end of expansion or power stroke. In that moment pressure of the exhaust gas reaches three to five bars. Thus, it is lost a potential to do additional useful work until pressure reaches the value of one bar.

A greater work would be obtained if the gas within the cylinder would expand until a pressure value of 1 bar with an increase in engine thermal efficiency [7]. Such a functioning cycle of internal combustion engine it is called *Over-expanded* cycle or *Atkinson cycle* and it successfully overcomes the disadvantage presented above.

Another solution, which augments the Atkinson cycle, is Miller cycle. This consists in modification of Atkinson cycle and implies a greater expansion process, thus greater useful work, than compression process within the same cycle of the internal combustion engine. The basic difference between Atkinson and Miller cycles is that while Atkinson needs a complicated combination of mechanism linkage to obtain greater expansion ration, Miller cycle uses a unique strategy of valve timing to obtain same results as previous cycle [9]. Thus, by closing the intake valve long before bottom dead centre or long after same point [9] the pump work will be considerably diminished while net work will reach a high value than usually. This modification of closing the intake valve may be reached, on series internal combustion engines, by using variable valve timing mechanisms.

Before detailing the influences that VVT&L involves over the internal combustion engine energetically and environmentally performances it is useful to define the system.

Thus, for a classical valve train system, Figure 1, the main parameters which define the system are constant: lift, duration and phase.

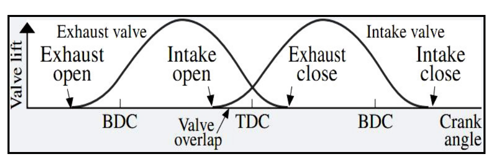

Fig. 1. *Lift, duration and phase for a classical valve train system* (*adopted from* [4])

It can be observed also that the valve overlap registers a constant value. Variable valve timing systems means that it is possible to vary the parameters defined above: lift, duration and phase like in Figure 2.

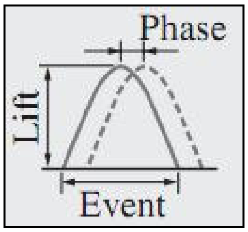

Fig. 2. *Variation of lift, phase and duration of a Variable Valve Actuation and Lift system* (*adopted from* [4])

From this main configuration could be obtained by using three strategies, the first one is called Variable Timing Control - VTC - and is achievable by modifying the phase; the second strategy is represented by Variable Valve Lift - VVL - which is achievable by modifying the value of valve's lift; the third strategy is obtained using the Variable Valve Event and Lift concept which assumes that duration, phase and lift are variable.

Now, after the concept of variable valve timing has been defined it would be useful to make a short description of which is the influence of variable valve train system over the engine's parameters.

The first performance item is represented by the *torque output* by means of charging efficiency and response. The factors which bring the main improvements are valve timing and lift and throttle-less effect using variable valve actuation functions like: early and late intake close which actuate direct on the effective compression ratio, late open in the intake valve in order to influence the motion of gas, exhaust valve close control for the burnt gas trapped in, positive valve overlap which also influences the burnt gas trapped in [4].

The second performance parameter is represented by *fuel consumption* characterized by indicated thermal and mechanical efficiency. The main improvement factors are compression ratio, gas motion, internal exhaust gas recirculation, fuel atomization, lower residual gas, pumping loss. This can be achieved by almost the same variable valve actuation functions [4].

The third and the last performance parameter are represented by the *exhaust gases* (hydrocarbons, carbon monoxide, nitrogen oxides) characterized by engine outlet, catalytic converter outlet and warm up. The main improvement factors are fuel atomization, suppression of fuel adhesion, internal exhaust gas recirculation [4].

Devices with which performances presented above could be obtained are: cam phaser classified by: position, construction, function; and devices to obtain variable lift and event, like for example variable lift tappet.

In order to understand better VVT&L strategy, next will be presented the classification of mechanisms.

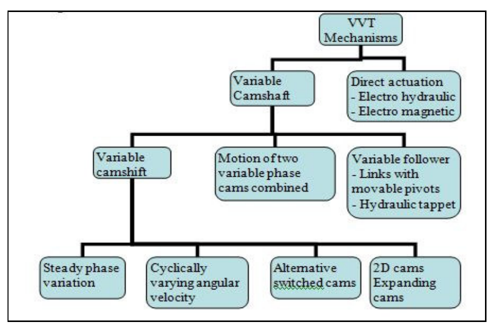

Fig. 3. *Classification of VVT&L mechanism* [7]

Quality of a VVT&L system may be appreciated by fulfilling the conditions given by the environmentally and ecologically performances, being defined as: high value of torque, low level of exhaust gases emission and low fuel consumption.

2.1. Modifying the opening moment of inlet valve

By opening early the intake valve combined with a modified valve overlap, the pressure in cylinder has a value bigger than the atmospheric pressure. In this condition back-flow results and a certain percent of burn gases and unburned fuel go in the intake manifold. In the next cycle, the percent above will be absorbed back in the cylinder, mixed with the fresh charge and shall combust together. Because of the presence of exhaust gases in the newer inlet charge, the overall temperature per cycle will be lower and the suitable conditions for generating NO_x will not be created, hence this quantity diminishes. The hydrocarbons present in the inlet manifold will be absorbed, mixed and burnt too.

This is how internal exhaust gas recirculation is created in order to decrease the amount of pollutant emissions. These strategies are available for both part load and full load. The arguments presented above are sustained by Figure 4. It can be observed that the quantity of NO_x decreases proportionally with the earlier moment of opening the valve.

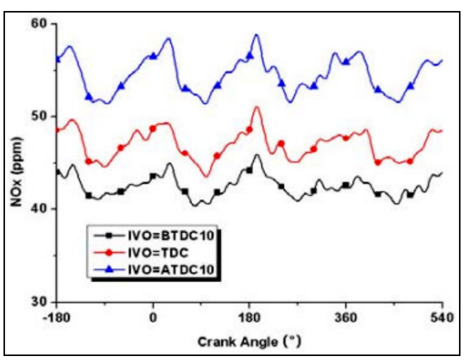

Fig. 4. *Comparison of types and functions of Variable Valve Actuation* (*adopted from* [2])

The CO_2 emission is reduced while the intake valve opening is retarded. When the intake valve opening timing was retarded, the amount of hot residual gas, which can promote combustion, as well as the volumetric efficiency, were reduced because of the reduced valve overlap and late intake valve closing [11].

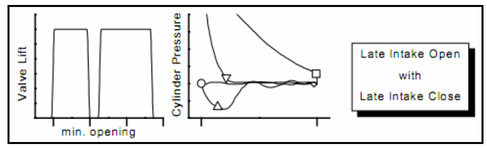

Fig. 5. *Influence of late intake valve open over pumping loses* (*adopted from* [8])

Opening late the intake valve, the gas within the cylinder is characterized by an increased motion, meanwhile flow rate at idle gets maximum values [7]. This is sustained by the Figure 5, in which it can be observed that the pumping loses area is quite impressive diminished.

2.2. Modifying the closing moment of inlet valve

It can be obtained by early closing or late closing of the valve. Combined with late intake valve open, the late intake close valve opening determines the pumping loses to decrease as we can see in Figure 2.

A supercharged engine with VVT&L reduces, by late intake close, the effective

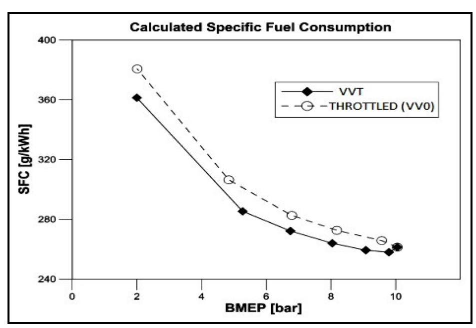

Fig. 6. *Break specific fuel consumption* (*bsfc*) *evolution for VVT and throttled engine* (*adapted from* [3])

compression ratio, during the piston moves towards the top dead centre.

Thus, it determines a very weak increase of pressure as well as a limit to compression work, in consequence the break specific fuel consumption register low values like in Figure 6 [3].

2.3. Modifying the opening moment of exhaust valve

Opening later the exhaust valve, within the exhaust stroke, it will lead to exhaust gas afterburning which will generate high temperatures and, in consequence the HC emission level will be lower [8].

For a supercharged engine with variable exhaust opening timing, advancing the opening moment, in order to acquire low speed torque and high speed power, influences the quantity of the energy flow to the turbine.

This fact is confirmed by figure number 4 which highlights an increase of engine's torque for speeds lower than 2000 rpm with earlier exhaust valve opening timings [5].

2.4. Modifying the closing moment of exhaust valve

Combining the closing moment of the exhaust valve with the intake valve opening it can be developed a new concept of valve overlap, the so called negative valve overlap. More details about this new principle will be given below.

2.5. Valve overlap

For the standard valve strategy in spark ignition and compression ignition engines involves high lift, long duration and positive valve overlapping while the modified valve strategy that is compatible with homogenous charge compression ignition combustion mode implies low lift, short duration and negative valve overlapping [6]. At medium loads and low to medium engine speeds, the higher valve overlap leads to better cylinder filling due to the inertia of the exhaust gases flowing from the cylinder to the exhaust manifold [10].

The negative valve opening is obtained by closing the intake valve earlier and opening the intake valve later. This concept it makes VVA devices to fit for diesel engines, especially for HCCI combustion, because offers the most efficient and promising approach to control the amount of hot exhaust gases and the effective compression ratio, and consequently the engine performance parameters [6].

3. Conclusions

It may be observed that using variable valve timing and lift systems the overall energetically and environmentally performance are improved by making better the efficiency at part load, decreasing the pumping loses, modifying the effective compression ratio, by making lower the emission of NO_x, CO and HC.

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