An Investigation of Variable Valve Timing application for controlling the HCCI Combustion.

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ABSTRACT
Homogeneous Charge Compression Ignition (HCCI) represents a promising combustion strategy for future engines Homogenous charge compression ignition (HCCI) has been identified as a promising way to increase the efficiency of the spark-ignited engine, while maintaining low emissions. The challenge with HCCI combustion is excessive pressure rise rate, quantified here with Ringing Intensity. In order to overcome these challenges a technology called Variable Valve Timing (VVT) was invented in nineties. This paper deals with the various application of VVT in order to find out the effect on the combustion in HCCI Engine.

HCCI lacks an easily identified combustion trigger and, when achieved via variable valve actuation (VVA), includes cycle-to-cycle coupling through the exhaust gas. This makes controlling the process decidedly non-trivial. To address these issues, the development of a closed-loop controller for HCCI combustion phasing and peak pressure was outlined. Results from both simulation and experiment show that cycle-to-cycle control of VVA-induced HCCI can be achieved using this physics-based approach. Correct combustion timing is crucial for proper engine performance in a Homogeneous Charge Compression Ignition (HCCI) engine. To stabilize unstable operating points, reject system disturbances and enable set point changes, it is necessary to use a combustion timing controller. In this, variable valve timing was used to control combustion timing, optimising fuel systems By means of the variable valve timing, residual gases were captured in cylinder to facilitate combustion timing control.

Key words – HCCI, combustion, VVT, pollutant emission, EGR ,CFD, Fuel injection

Introduction:

The Internal Combustion (IC) Engine is perhaps the most wide-spread apparatus for transforming liquid and gaseous fuel to useful mechanical work. The reason why it's so well accepted can be explained by its overall appearance regarding properties like performance, economy, durability, controllability but also the lack of other competitive alternatives. The demand for reduced fuel consumption and increased efficiency becomes more important when the fuel prices are rising. Lately the green house effect has set new challenges to further increase the efficiency of the internal combustion engine. Increased environmental concern has focused more and more on the released exhaust pollutants from engines.

The dream of every engine designer is to find a combination of the diesel engine and the spark ignited engine that only inherit the good properties of the diesel and SI engine i.e. efficiency like a diesel engine and exhaust emissions that are as clean as from the SI engine, or at least possible to after-treat to the same level. This can be reached with Homogeneous Charge Compression Ignition (HCCI). HCCI combustion was first applied to two-stroke engines [1], [2] with improvement in fuel efficiency and combustion stability. When HCCI as applied to the four-stroke engine, the fuel efficiency could be improved up to 50 % compared to the SI engine [3].

Homogeneous charge compression ignition (HCCI) uses a lean premixed air-fuel mixture that is compressed with a high compression ratio. During the end of the compression stroke, ignition occurs through self-ignition in the whole combustion chamber at once. Since the mixture is lean, the maximum temperature, both locally and overall, becomes low compared to other engines, which effectively reduces NOx formation

. Although stable HCCI operation and its substantial benefits have been demonstrated at selected steady-state conditions, several technical barriers must be overcome before HCCI can be widely applied to production automobile and heavy-truck engines. To Overcome the technical challenges to practical HCCI engines requires an improved understanding of the in-cylinder processes, an understanding of how these processes can be favourably altered by various control techniques, and the development and testing of appropriate control mechanisms.

The major advantage of HCCI combustion is realized by eliminating the formation of flames. That results in much lower combustion temperature. As a consequence of the low temperature, the formation of NOx (nitrogen oxides) is greatly reduced. The lean burn nature of the HCCI engine also enables un-throttled operation to improve engine fuel economy. Unfortunately, HCCI combustion is feasible only over a limited engine operational range due to engine knock and misfire. To make a HCCI engine work in an automotive internal combustion engine, it has to be capable of operating at both SI combustion mode at high load and HCCI combustion mode at low and mediate load ([4] and [5]). This makes it necessary to have a smooth transition between SI and HCCI combustion modes.

Achieving the HCCI combustion and controlling the mode transition between SI and HCCI combustions in a practical engine require implementation of enabling devices and technologies. There are a number of options, and the necessary prerequisite for considering any of them is their

ability to provide control of thermodynamic conditions in the combustion chamber at the end of compression. The range of devices under consideration includes variable valve actuation (cam-based or cam- less), variable compression ratio, dual fuel systems (port and direct fuel injection with multiple fuel injections), supercharger and/or turbocharger, exhaust energy recuperation and fast thermal conditioning of the intake charge mixture, spark-assist, etc.

Variable Valve Actuation can be used for control of the effective compression ratio (via the intake valve closing time), the internal (hot) residual fraction via the negative valve overlap (recompression) ([6] and [7]), or secondary opening of the exhaust valve (residual re-induction) ([6] and [7]). In addition to providing the basic control of the HCCI combustion, i.e., ignition timing and burn rate or duration, the VVT systems plays a critical role in accomplishing smooth mode transitions from SI to HCCI and vice versa ([8], [9] and [10]).The main focus of the paper is investigate the application of VVT with combustion analysis.

Strategic Approaches of VVT for HCCI:

Continually variable valve timing (VVT) systems used in internal combustion engines were developed in nineties and have since been widely used due to the growing fuel economy demands and emission regulations. VVT system improves fuel economy and reduces emissions at low engine speed, as well as improves engine power and torque at high engine speed.

The idea behind VVT is simple - alter the timing and/or size of the intake and exhaust ports at different engine RPMs to ensure that the engine is as efficient as possible throughout its range of operating speeds. There are two types of variable valve timing, or VVT – cam phasing and cam changing. VVT could be implemented in an engine with mechanical, magnetic, or hydraulic valve actuators [11]. Recently, researchers at Stanford University, using an electro-hydraulic VVT system, have shown that HCCI combustion can be induced in an engine with a relatively low (10:1) compression ratio [12]. Stanford also showed that the VVT system could be used to control combustion timing and to switch between SI and HCCI operation from one cycle to the next.

Stanford University -- Variable Valve Timing

Stanford University's HCCI studies were focused on how to use Variable Valve Timing (VVT) in order to:

1) Induce HCCI over a broad range of operating conditions without the need to throttle.

2) Incorporate HCCI into a multi-combustion-mode engine capable of meeting consumer demands for power, PNGV targets for efficiency, and Tier 2 standards for emissions.

Both port-fuel injection strategies (minimal cost) and gasoline direct-injection strategies were envisioned with emphasis on direct-injection engines. Gasoline was the fuel of choice in that application, and achieving HCCI with low compression ratio and with high-octane fuels was a central aspect of this effort. Key issues that must be addressed include the phasing of the HCCI combustion with piston motion, the dynamic range over which HCCI operation can be achieved, and the development of robust control strategies to manage transitions between optimal combustion regimes as speed/load requirements vary. Achieving HCCI with low compression ratio (10:1) and with high-octane fuels (propane, octane number = 104) via re induction (i.e, re-introducing hot combustion products from the previous cycle) has been demonstrated at Stanford. The results were obtained using an electro-hydraulic VVT system developed at Stanford and shown in Figure 2.

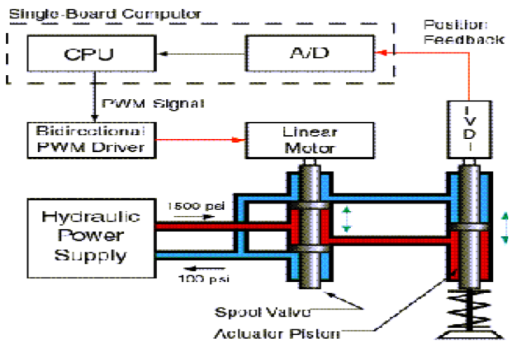

Fig **1.** Schematic of the Stanford VVT System used to induce HCCI by exhaust product re induction.

This system allows arbitrary lift profiles to be executed by both the intake and exhaust valves. Using this system, a single engine can operate as a conventional, spark-ignition (SI) engine on one operating cycle and execute a completely different mode of combustion on the next cycle. Current capabilities include execution of four of the six major combustion strategies on a cycle-by-cycle basis: homogeneous-charge SI combustion, lean-burn SI combustion, residual-diluted SI combustion, and HCCI. All of these modes can be operated with or without throttling. When throttling is desired, it is provided by the intake valve. All modes can also be operated with advanced breathing strategies including optimal phasing at any engine speed, early- and late-intake-valve closing (Miller cycle), and/or modification of the effective expansion ratio through modification of exhaust valve closing.

Figure 2 shows how the system can be used to alternate between combustion modes on a cycle-by-cycle basis. In this example, late exhaust valve closing (holding the valve open during the intake stroke) permits enough hot exhaust to be inducted with the fresh charge to cause compression ignition. Current research centres around exploring the regimes in which HCCI can be induced by late exhaust valve closing as well as late intake valve opening. Values of Integrated Mean Effective Pressure (IMEP, a measure of the work produced by combustion) ranging from 30 to 60 percent of wide-open throttle, SI-engine combustion have been achieved using this strategy. In the next phase of this work, advanced valve actuation strategies will be employed to expand the operating range of HCCI, and studies aimed at providing optimal phasing of heat release will be conducted. VVT will also be used in conjunction with direct injection in order to demonstrate integration of HCCI into a multimode combustion engine that includes stratified charge and possibly diesel-type fuel injection and combustion. In addition to measurements in conventional (metal) engines, an optically accessible engine tailored for investigating the key parameters of direct injection HCCI with exhaust re induction is under construction. The data from this experiment will help researchers to develop a quantitative (computational) capability to predict the performance of these new hybrid engines, and it will enable designers to better understand the processes that lead to optimal system performance.

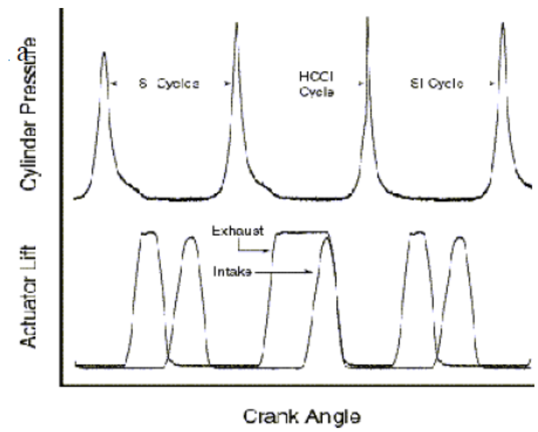

Fig 2. Multi-combustion-mode operation on a cycle-by-cycle basis; the third cycle is HCCI induced by late exhaust valve closing**.**

Conventional electronic-hydraulic VVT ([13] and [14]), also called hydraulic VVT, is the most widely used in the industry today. The hydraulic VVT systems require minor changes when applied to a previously non-VVT valve-train [13], which makes design and engineering relatively easy. However due to its mechanism, the hydraulic VVT system also has its limitations [15]. The response and performance of the hydraulic VVT system are significantly affected by the engine operating conditions such as engine oil temperature and pressure. This leads to the study of other variable valve-train system, such as electromagnetic [16], hydraulic [17], electro-pneumatic [18], and electrical motor driven planetary gear systems ([19] and [20]). Electric motor driven VVT operational performance is independent of engine oil temperature and pressure [15]. Comparing to hydraulic VVT system, electric motor driven VVT system is less limited to engine operating conditions and therefore gives better performance and better emission in a wider operational range. Especially, since the electrical VVT is independent of the engine oil pressure, the response time is greatly improved.

The planetary gear VVT system was studied [21] consists of four major components (see Fig. 3).

Ring gear, serves as VVT pulley, is driven directly by crankshaft through a timing belt at half crankshaft speed. Planet gear carrier is driven by an electric VVT motor. Planet gears engage both ring and sun gears. Sun gear is connected to the camshaft. The sun and planet gears are passive components that obtain kinetic energy from carrier and ring gears. Comparing to other components, the inertia of engine fly wheel and crank shaft is very large. As a result, dynamics of the ring gear is ignored in this study. All other components have known mechanical properties and their dynamics are considered in the modelling.

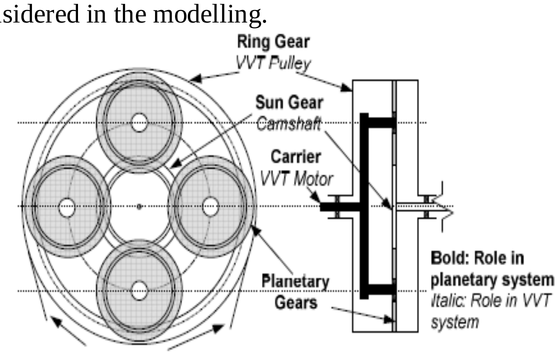

Fig.3: Electric planetary gear VVT system

In order to operate engine in SI and HCCI combustion modes, a the electrical VVT system was selected to control the engine valve timings . In order to control the electric planetary VVT system, a feedback controller was introduced [20]. Due to the steady state and transient control accuracy requirements of the HCCI combustion, the closed-loop electric VVT system needs not only to meet steady-state performance requirement but also to track a desired trajectory during the combustion mode transition. Therefore, a feedback controller with feed forward control was developed [21]. In the studied VVT system, the cam phase is the integration of speed difference between the electric VVT motor and crankshaft. This leads to using the rate of the reference cam phase as feed forward command. Output covariance control (OCC) ([22][23], and [24]), an $H2$ controller, was used in feedback to reduce the tracking error. Performance of the OCC controller was compared with well-tuned proportional-derivative (PD) controllers, and the OCC with feed forward provides better cam phase tracking performance than PD controllers. Different cam phase sample rates were also studied and results show that 4 samples per engine cycle are sufficient for OCC feedback.

An electric VVT system with planetary gear train was model based upon individual component dynamics and kinematics. A closed-loop OCC (output covariance constraint) control with feed forward control was proposed to reduce the cam phase tracking error during SI (spark ignited)and HCCI (homogeneous charge compression ignition) combustion mode transition. Due to the physical characteristics of the electric VVT system, the filtered derivative of the cam phase reference was used as the feed forward control. Comparing with the well tuned PD controllers, simulation results show the OCC controller provides fast response with low overshot and low tracking error. With the OCC controller the cam phase signal sampled at 4 times per engine cycle is sufficient to meet the maximum tracking error requirement of less than 1.5 degree.

Engine speed	Cycle Number	Error (Deg)		
		PD	PD w/ ff	OCC w/ ff
1500rpm	1	+3.5	+0.9	-0.5
	2	+2.3	-0.8	-1.0
	3	+1.1	-1.5	-0.9
	4	-0.1	-1.5	-0.8
2000rpm	1	+2.8	+1.6	+1.3
	2	+1.8	-0.2	-0.5
	3	+0.8	-1.2	-0.6
	4	-0.1	-1.5	-0.8

Tab. 1: Output comparison at end of each cycle

Sample Rate	Cycle Number	Error (Deg)		
		PD	PD w/ ff	OCC w/ ff
8/ cycle	1	+2.6	+1.2	+0.3
	2	+1.7	+0.0	-0.3
	3	+0.9	-0.6	-0.4
	4	+0.1	-0.9	-0.4
16/ cycle	1	+2.6	+1.8	+1.0
	2	+1.8	+0.7	+0.5
	3	+0.9	-0.1	+0.2
	4	+0.1	-0.5	+0.0

Tab. 2: Output comparison at 1500rpm with different sample rate

One of the main challenges in HCCI engines is achieving the desired combustion phasing and work output, during both steady state and transient operation. HCCI has no specific event that initiates combustion, like spark in SI engines or fuel injection in diesel engines. In addition, for residual-affected HCCI, cycle-to-cycle coupling exists through the exhaust gas temperature. To address the lack of a direct combustion initiator and cycle-to-cycle dynamics, it is generally accepted that closed-loop control will be necessary.

Several approaches to closed-loop control of HCCI engines have been demonstrated ([25], [26], [30], [27]). Agrell et. al. [25] used valve timings to effectively alter the compression ratio and control phasing. Haraldsson et. al. [26] modulated the fuel amount to vary IMEP while altering the mixture ratio of two fuels to control phasing. Olsson et. al [1] took a similar approach but used compression ratio instead of fuel mixture to shift phasing. While all of these authors used tuned PID controllers, Shaver et. al. demonstrated that HCCI controllers could also be synthesized using physics-based models [27].

The ability to phase HCCI and control work output of the system a physics-based closed-loop control was studied on a single cylinder research engine as a direct consequence of being able to vary the valve timings with the VVA system. The approach was to leave the exhaust valve opening (EVO) time fixed and modulate the exhaust valve closing (EVC), intake valve opening (IVO) and intake valve closing (IVC) times to control the mass flows. IVC dictates the effective compression ratio by determining the start of compression. By modulating IVO and EVC for a given IVC, the amounts of inducted reactant and re-inducted product can be set for any given engine cycle. The three valve timings together therefore allow independent control of both the ratio of re-inducted products to fresh reactants and the effective compression ratio. By influencing the effective compression ratio, IVC determines when the reactant and re-inducted product gases begin to be compressed. This, in turn, influences combustion timing through the chemical kinetics. While the exact kinetics are quite complex, a simplified Arrhenius rate expression captures experimental data quite well ([28], [29]) and offers a very simple understanding of the process. In short, given two mixtures with identical ratios of re-inducted products and reactants at the same temperature, early IVC leads to a higher level of compression and earlier phasing of combustion. In this way, both desired phasing and load can be controlled simultaneously by varying IVO, EVC and IVC.

The first step in model-based control was the development of a mathematical system description which captures the relevant physics. A physics-based control-oriented system model for peak pressure and combustion phasing was formulated to address this need. The framework for modelling HCCI combustion in a simple way involves partitioning the engine cycle into five stages, as shown in Figure 4: mixing of reactant and re inducted product gases during a constant pressure, adiabatic induction process; isentropic compression to the point where combustion initiates; constant volume combustion with heat transfer to major products; isentropic expansion to the point where the exhaust valve opens and isentropic expansion through the exhaust valve.

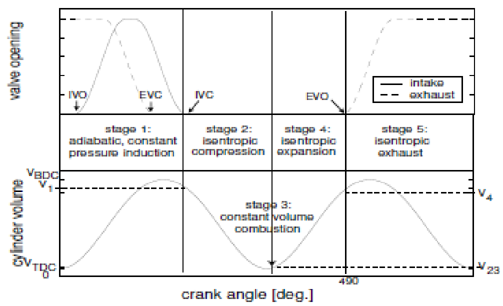

Fig. 4. General view of partitioned HCCI cycle

Since the molar ratio of re-inducted products to fresh reactants can be controlled through some combination of IVO and EVC for a given IVC, this ratio was chosen as one of the inputs to the model. Additionally, since the effective compression ratio can be controlled with IVC, the IVC timing was chosen as the second control input. A mathematical relation for the peak pressure was formulated by discretizing the various processes which occur during a HCCI combustion engine cycle, then linking them together. Combustion phasing was modeled by making some simplifications to the integrated Arrhenius model presented in previous work ([9], [10]). With the control-oriented model for peak pressure and combustion phasing, feedback linearization was then used to synthesize a nonlinear controller. In order to implement the control strategy in simulation and experiment, a map from the desired in-cylinder ratio of fresh reactant charge and re-inducted products at a given IVC valve timing to the required IVO and EVC valve timing was realized through simulation of the induction process. Implemented on a more detailed 10-state model, the control law was able to successfully control both combustion phasing and peak pressure on a cycle-to-cycle basis, therefore indirectly controlling work output. The control approach was further supported by experiments illustrating the simpler case of tracking desired peak pressure at constant phasing. The results of both simulation and experiment were very promising; demonstrating the effectiveness of a physics based cycle-to-cycle approach to HCCI control.

Results for this approach are shown in Figure 5 and demonstrate both mean tracking and a substantial reduction in the cyclic dispersion compared to the uncontrolled case. The controller introduces more stability, and as a result, expands the applicable operating range for HCCI. These results verify that physics-based models can be used to synthesize controllers which operate on a cycle-to-cycle basis.

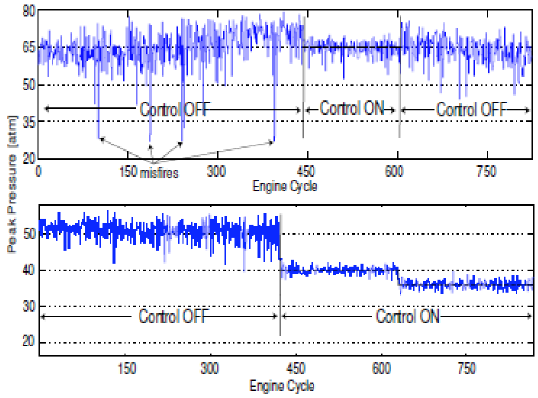

Fig. 5. Experimental control results, dashed lined - desired peak pressure, top: response to no change in desired mean pressure, bottom: response to step changes in desired peak pressure

While the cycle-to-cycle dynamics and chemical kinetics of VVA-induced HCCI are complex, the essential characteristics for control can be captured in a relatively low-order model. The results from both simulation and experiment show that cycle-to-cycle control of VVA induced HCCI can be achieved using a physics-based approach.

Promising Improvements with EGR for HCCI:

Homogenous charge compression ignition (HCCI) has been identified as a promising way to increase the efficiency of the spark-ignited engine, while maintaining low emissions. The challenge with HCCI combustion is excessive pressure rise rate, quantified here with Ringing Intensity. Turbo charging enables increased dilution of the charge and thus a reduction of the Ringing Intensity. In order to extend the HCCI operational range and to reduce the high pressure rise rate with: increased boost from turbo charging, external EGR and different injection strategies were used [31].

The test engine was an in-line four cylinder gasoline engine with a total displacement of 2.2*L*.The cylinder head was a 4-valve design with a pent-roof combustion chamber. To achieve HCCI combustion the engine was run with negative valve overlap (NVO), with short lift and short duration camshafts designed for a naturally aspirated (NA) HCCI engine. The variable valve timing (VVT) was controlled by hydraulic actuators at the camshafts, meaning there was a separate 50 crank angle degree (CAD) adjustment on both intake and exhaust valve timings. The engine was turbocharged by a variable geometry turbine (VGT), the VGT position was controlled by an electric actuator.

When load is increased by this turbocharged HCCI engine the operating parameters all the time has to be balanced against each other. For example if we need to increase the load range where the pressure rise rate is too high the CA50 can be delayed if the CoV is stays low, the back pressure goes up from the delayed combustion timing and therefore the intake pressure and temperature is increased. The camshaft timing has to be changed to keep CA50 position meaning a later EVC is needed and therefore EVO comes later and there is risk for increasing throttling losses with these short duration camshafts. If the CA50 is delayed from MBT there will also be a loss in efficiency. On the other hand if we compare to a NA HCCI engine, we can operate on a combustion timing closer to MBT at high load with this boosted HCCI engine for the same RI number, leading to improved efficiency with right turbocharger sizing. as per Fig. 6 there is a comparison of possible load range between the turbocharged set-up and a naturally aspirated HCCI set-up; with an OEM style exhaust manifold. The limitations are the same and the control strategy and operating is the same, by turbo charging the possible load range is increased in the whole speed range.

The HCCI engines use different indirect strategies to control the start of the combustion. The exhaust gas recirculation (EGR) is one of the most used methods. The internal EGR is obtaining by closing the exhaust valve before the top dead centre (TDC) an opening the intake valve after the TDC.

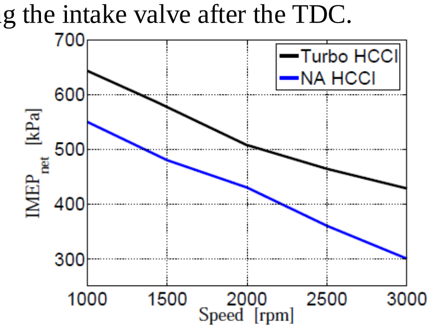

Fig 6: Maximum load: turbocharged vs. NA HCCI

The burned gases trapped inside the cylinder are compressed by the motion of the piston to the TDC. The valve lift strategy used to obtain the internal EGR is shown in figure 7. When the internal EGR is used, the intake and exhaust valve overlap disappears.

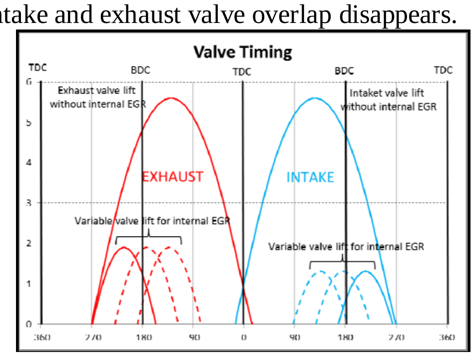

Fig 8. Valve timing

In fig 9 the valve lifts used to study the influence of the internal EGR on the cylinder pressure are shown. Four operating points are used, where the intake valve lift is the same for al the operating points while the exhaust valve lift is displaced to simulate different EGR rates. The intake valve is opening at 76 ° CA and the exhaust valve is opening at 567° CA for the first operating point, at 587° CA for the second operating point, at 607° CA for the third operating point and at 627° CA for the last operating point.The engine speed was maintained constant during all the four operating points at 2000 revolutions per minute (rpm).

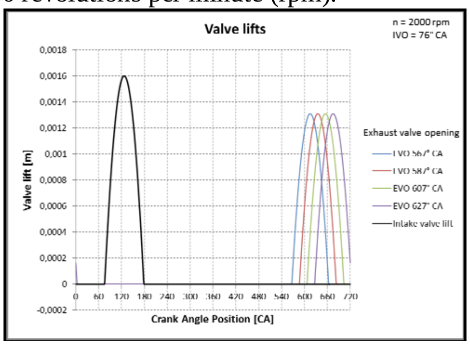

Figure 8. Valve lifts-variable exhaust

The best performances of the engine can be achieved when the intake valve lifts are fine tuned depending on the exhaust valve lifts. The main objective is to ensure the proper timing for the opening of the intake valve when the pressure from the intake manifold is similar with the cylinder pressure. The best timing is obtained when no burned gases from the cylinder are passing into the intake manifold and the maximum quantity of air is aspired during the intake process.

The amount of trapped burned gases has a huge influence on the combustion. When the EGR rate is too low the conditions needed for the auto ignition of the airfuel mixture are missing so there will be no combustion. On the other hand, the trapped gases are replacing a part of the fresh air which can be aspirated into the cylinder so the performances of the engine can be reduced using a higher EGR rate.

A variable valve timing (VVT) mechanism is applied to achieve premixed diesel combustion at higher load for low emissions and high thermal efficiency in a light-duty diesel engine. By means of late intake valve closing (LIVC), compressed gas temperatures near the top dead centre are lowered, thereby preventing too early ignition and increasing ignition delay to enhance fuel-air mixing. The variability of an effective compression ratio has significant potential for ignition timing control of conventional diesel fuel mixtures. At the same time, the expansion ratio is kept constant to ensure thermal efficiency. Combining the control of LIVC, exhaust gas recirculation (EGR), supercharging systems, and high-pressure fuel injection equipment can simultaneously reduce NO_x and smoke. The NO_x and smoke suppression mechanism in the premixed diesel combustion is analysed using a three-dimensional computational fluid dynamics (3D-CFD) code combined with detailed chemistry. LIVC can achieve a significant NO_x and smoke reduction due to lowering combustion temperatures and avoiding local overrich regions in the mixtures respectively.

Controlled Auto-Ignition (CAI), also known as Homogeneous Charge Compression Ignition (HCCI) has been receiving increased attention due to its potential to improve fuel economy and reduce emissions in gasoline internal combustion engines. The fuel economy results mainly from the fact that it can operate without throttling losses at part load. It is characterized by a flameless and fast combustion and, to avoid excessive rates of heat release, requires high levels of charge dilution. Ultra low Nitrogen Oxides (NOx) emissions result due to the low combustion temperatures and generally low CO emissions have been observed under lean CAI conditions, compared to SI. There are several different strategies used to facilitate CAI with the objective of creating, near firing TDC, conditions that will cause the mixture to spontaneously ignite. Variable valve actuation is currently the most attractive technology capable of providing sufficient thermal energy, by the means of residual gas, to trigger auto-ignition. The valve techniques employed for CAI can be divided into 2 main categories:

• The exhaust re-breathing strategy, where exhaust gas reenters the cylinder from one of the ports.

• The exhaust recompression strategy, where a significant
fraction of the exhaust gas is trapped in the cylinder.

The valve profiles incorporated in the model are suitable for
the exhaust gas recompression strategy. The exhaust valves
close well before TDC, to trap exhaust gas and the inlet valves open well after TDC, to avoid significant backflow into the intake manifold. The absence of any valve overlap is called Negative Valve Overlap (NVO). It would be relatively easy, however, to replace the valve profiles with ones suitable for the exhaust gas re-breathing. The ignition timing in CAI is almost solely determined by the chemical kinetics in the cylinder. Even low-order chemistry mechanisms may include up to 100 species and 500 reactions.

A non-linear low-order model of variable valve actuated CAI combustion has been built and validated in steady state. Potential controlled variables, such as the work output and the combustion phasing show reasonably good agreement with experimental values. The inclusion of the gas exchange processes in the core of the model allows it to run continuously by switching between the different regimes of the cycle. It is based on the in-cylinder dynamics and assumes constant manifold pressures. Other main simplifying assumptions are: Constant mol fractions of gas constituents during the gas exchange processes, heat transfer to the cylinder walls only by convection, no account for the fuel heat of vaporization, only main combustion products and reactants present in the cylinder. Controlled Auto-Ignition was attained by diluting the mixture with exhaust gas trapped in the cylinder, as a result of an early Exhaust Valve Closing.

CONCLUSION

As with traditional piston engines, VVT engines use cams on a camshaft to drive the flow of air into the intake and exhaust valves. The timing of this valve lifts directly affects how much air is taken in during each engine cycle. At times when the engine requires more air flow (for example high speeds or acceleration), a traditional piston engine often does not allow enough air to flow during each cycle, resulting in lower output performance. Conversely, a traditional piston engine that has been designed to feature longer exhaust and intake cycles will result in reduced fuel efficiency at slower speeds.

The valve train system has a higher importance at the HCCI engines. Beside its main purpose, to ensure the exhaust of the burned gases and the intake of the fresh air, the valve train system has to ensure the conditions needed to obtain the homogeneous combustion and also to control the auto ignition delay. Due to this task, more complex mechanisms capable of modifying the valve lifts while the engine is running are used. The best performances of the engine can be achieved when the intake valve lifts are fine tuned depending on the exhaust valve lifts. The main objective is to ensure the proper timing for the opening of the intake valve when the pressure from the intake manifold is similar with the cylinder pressure. The best timing is obtained when no burned gases from the cylinder are passing into the intake manifold and the maximum quantity of air is aspired during the intake process.

It is observed that using different cam phase positions the swirl number generated in the cylinder changes. 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 The amount of trapped burned gases has a huge influence on the combustion.

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.

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