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Model based Study on Effects of Valve Lifts and Events on the Performance of an Engine

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Abstract - *A conventional 4-stroke engine uses intake and exhaust valves to control the flow of air into and out of the combustion chamber, these valves significantly dictate the amount of power that can be produced by a particular engine. Recently developed engines are integrated with modified cams to offer variable valve lifts and timings at different operating speeds in order to achieve optimum performance characteristics at all engine speeds. This paper seeks to provide an overview of obtaining valve profiles for any engine with the help of mathematical modelling, basic parameters used in the specification of valve timing, and its effects on engine performance. The objective of this paper is to study influences of intake and exhaust valves' lifts, overlap, and timing w.r.t crank angle on the performance of a single-cylinder engine using a one-dimensional (1-D) model of KTM 390 engine which is developed virtually in GT-Power and is used to simulate the engine performance over a rpm range with different valve profile inputs. Variables like volumetric efficiency and brake torque produced by the engine are taken into consideration to compare the performance.*

Key Words: 1-D model simulation; Valve timing; Valve lift; Engine Performance; Single-cylinder Engine

1. INTRODUCTION

An internal combustion engine produces mechanical power by combusting fuel with an oxidizer (usually air) inside a closed chamber. The expansion of the hot and high-pressure gases pushes a piston and this linear motion is in turn converted to rotational motion using a crankshaft. A typical IC (internal combustion) engine running on a 4-stroke cycle would use intake and exhaust valves to transport the air-fuel mix in and residue out of the chamber.

Each stroke is defined as upward or downward motion of the piston. For the first stroke, the piston moves down and the air-fuel mix enters the combustion chamber through the open intake valve. After the piston reaches BDC (Bottom Dead Centre), the intake valves shut and the piston moves upwards compressing the air-fuel mix to facilitate ignition. As the piston reaches TDC (Top Dead Centre), the spark plug ignites the compressed air-fuel charge and the piston is forced down due to the energy released in the combustion process to produce power. After the piston reaches to the BDC its time to drain the burnt air-fuel mix, and the exhaust valve is opened to pump out the exhaust gases with the piston moving upwards.

The valve opening and closing events are crucial to produce power by burning the fuel. Intake valves can be considered as gates which allow fresh air-fuel mixture to enter into the combustion chamber and the variation in lifts, timing, and duration will affect the performance output of the engine; similarly, exhaust valves are the ones that are responsible for draining the burnt air fuel mixture from the combustion chamber to the ambient environment. Conventionally, these valves open and close with the help of camshafts that rotates at half the speed of the crankshaft and is connected to the crankshaft using belts or chains often known as timing belts. The cams are designed for specific valve lift profiles and define the opening and closing events of the valves. Duration is defined as the angle of the crankshaft rotation between the opening and the closing of the intake or the exhaust valve. At lower rpms (revolutions per minute) valve duration is more, whereas, at higher rpms duration is less. Hence, with the dynamic engine rpm the camshaft rpm and valve-open duration vary accordingly. [1,2]

1.1 Valve Timing Diagram

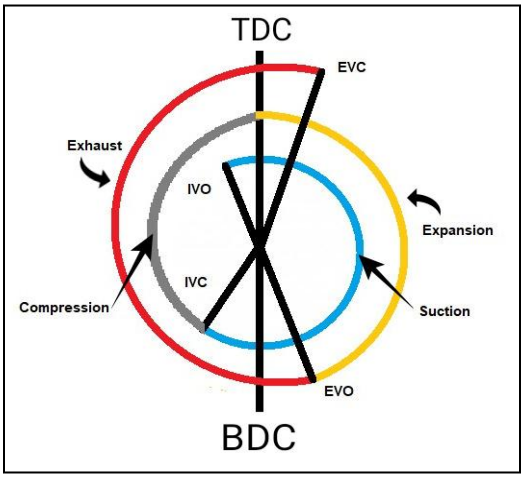

Fig -1: Valve Timing Diagram

Fig-1 shows a conventional valve timing diagram for a 4-stroke petrol engine and it is evident that the intake and exhaust valves don't open exactly at TDC and BDC as discussed in the theory above. With a conventional valve train, the valves take some time to lift form it's seating due to inertia and provides a significant restriction to the gas flow hence the theoretical events need to be shifted ahead or before the theoretical positions w.r.t the piston.

1.1.1 Valve Events

IVO (Intake valve opening) - The timing of IVC is one of the factors affecting the valve overlap period. If the intake valve is open before TDC, the exhaust gases might travel into the intake port and affect the volumetric efficiency as we will not be able to pack as much fresh air intake into the cylinder, and this might affect the full-load performance. Whereas, if the valve is opened after TDC it can restrict entry of air-fuel mix and cause a drop in in-cylinder pressure as the piston has already started moving down after reaching TDC. With an early IVO, BMEP (Brake Mean Effective Pressure) might decrease due to more residual gases remaining due to long overlap period, and with a late IVO, BMEP decreases due to low volumetric efficiency because the induction is affected.

IVC (Intake valve closing) - The amount of fresh charge that gets trapped inside the combustion chamber is greatly dependent on the timing of IVC. For maximum torque the intake valve should ideally close where the greatest mass of fresh charge is inside the chamber. Closing the valve before or after this results in a low volumetric efficiency. On moving the IVC farther than BDC, high-range torque is improved, whereas, moving it closer to the BDC improves low-speed torque. An early IVC reduces the mass of the air-fuel mix flowing into the cylinder. At the same time, at low engine speeds, a later IVC might mean that some air flows back into the intake manifold but at higher speeds, there might still be a positive flow with the same IVC.

EVO (Exhaust valve opening) - As the exhaust valve is opened, the high pressure inside the cylinder escapes to the exhaust system. Hence in order to achieve maximum work from the exhaust gases it would be desirable to open the exhaust valve at or after the piston reaches BDC, opening it earlier would lead to lowering of the pressure of the gases inside the chamber, whereas a later opening increases the exhaust back pressure and the piston has to work against the pressure of gases inside the chamber to push them out, both of them would lead to a reduced work output. The choice of EVO is hence a trade-off between the work lost by allowing the gases in the cylinder to escape before they fully expand, and the work required to raise the piston to TDC against the pressure in the cylinder.

EVC (Exhaust valve closing) - This is the other event to define valve overlap, hence, this event has a significant effect on how much exhaust gas is left in the cylinder at the start of the intake stroke. To achieve most out of the engine at high load conditions, all the exhaust gases need to be flushed out of the chamber. For the part-load conditions it might be beneficial to retain some of the exhaust gases in order to save fuel and improve part-load emissions hence it may be desired to advance the EVC towards the TDC, whereas, a late EVC might mean much of the fresh intake charge is lost to exhaust and the cylinder becomes over-scavenged. [2,3,4,5,6,7]

1.2 Valve Lift

Valves' peak lift greatly affects the amount of air entering and leaving the combustion chamber and as a result it greatly influences the engine performance. In a conventional valve train, design constraints like time taken to open the valve up to its peak lift and the acceleration required might define the peak lift for an engine. At higher speeds the valves don't have much time to open fully and this can hamper the engine's high-range performance.

Low values of peak lift can significantly restrict the air flowing through the valves, whereas, higher lifts might mean that the air can flow through the valves freely. This also affects the low-end performance. Low lifts allow the air to flow at higher speeds this improves fuel mixing and combustion. Hence, to achieve maximum performance the peak lifts need to be tweaked to a point where the flow remains unrestricted and has sufficient velocity for effective fuel mixing. It can be said that peak lift for any valve is therefore a compromise between low speed and high-speed performance. [8,9,10]

2. MODELLING OF VALVE-LIFT PROFILES

2.1 Methodology

The conventional valve lift profile is a sinusoidal function of various parameters like open timing instant, maximum lift, open duration period, and crank angle. The model has been tested to be accurate in various studies and thus has been considered for this study as well. [11,12]

$$L(\Theta) = L\,sin^2\left(\pi\,\frac{\Theta-\Theta_{VO}}{\Theta d}\right) \qquad \text{...Eqn.-1}$$

Here, L is the maximum lift, Θ_{VO} is the crank angle degree when valve opens and Θ_d is the crank angle degree duration from valve opening to valve closing.

2.2 Model preparation

The use of numerical computing software like MATLAB greatly reduces the effort and time taken to achieve the values to plot a valve lift profile. Simulink helps to run dynamic simulations and get the values for every degree change in crank angle in this case. The Simulink model is prepared based upon the mathematical Eqn.-1, and the geometric and other engine specifications for KTM390 along with the data found from the engine service manual. [13,14]

The model is having two conditions for the crank angle to specify the duration of intake and exhaust valve opening duration. The output was recorded at 1-degree intervals and stored in a file, which was later used to prepare the graphical representations.

Table -1: Valve Specifications

Valve Specifications	
Engine parameters	Values
No. of intake valves	2
No. of exhaust valves	2
Intake valve open	2deg Before TDC
Intake valve closing	44deg After BDC
Exhaust valve open	43deg Before BDC
Exhaust valve closing	3deg After TDC
Intake valve Diameter	36mm
Exhaust valve Diameter	29mm
Maximum intake valve lift	9mm
Maximum exhaust valve lift	8.8mm

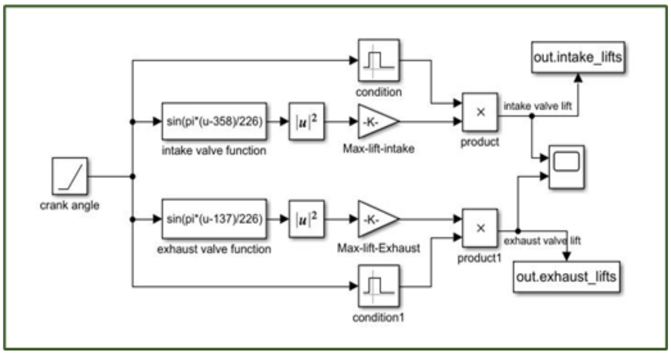

Fig -2: Simulink Model

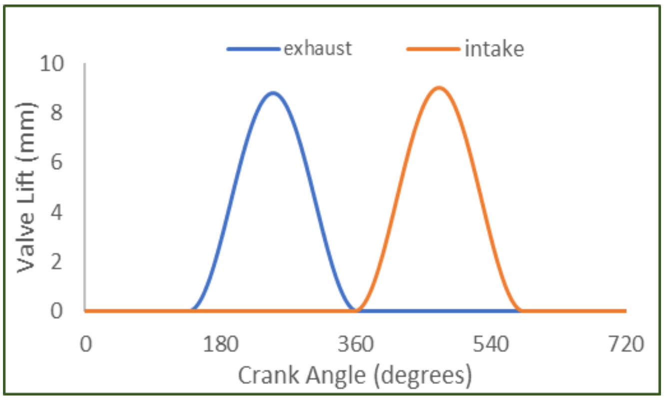

Chart -1: Valve Lift Profile for KTM390

3. GT- POWER MODEL PREPARATION AND SIMULATION CASE SETUP

In this study, the numerical analysis of a single-cylinder engine is performed using a commercially accepted engine simulation software package, this helps in reducing the time and cost involved in manufacturing cams for different valve profiles and then testing the engine on a dynamometer.

The 390cc KTM single-cylinder internal combustion engine is a high-performance engine with shorter strokes to allow high revs. It has electronically controlled port injection and hence, was selected for this study. The engine has two intake valves and two exhaust valves for the cylinder, which are controlled by two overhead camshafts. This setup is also known as Dual Overhead Camshaft (DOHC).

The 1-D model has been developed based on the specific engine geometry and parameters listed in Table-2. [13,14]

Table -2: Engine Specifications

Engine Specifications	
Engine Geometries	Values
No. of cylinders	1
Bore	89mm
Stroke	60mm
Cubic Capacity	373.3cc
Connecting Rod length	105mm
Compression Ratio	12.88:1
Air-Fuel ratio	14.7

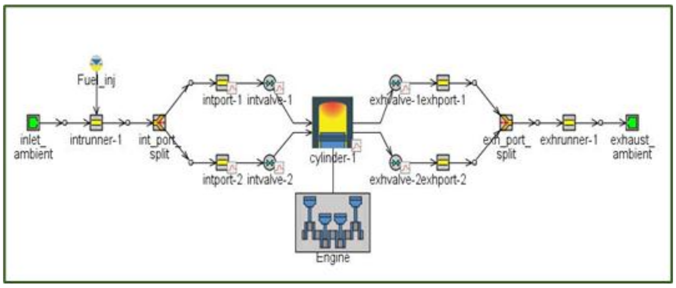

Fig -3: GT-Power Model

Fig-3 shows the engine and cylinder setup in the middle, the air enters through inlet_ambient which resembles the ambient environment and flows through a 150mm long intake runner. At the end of intrunner-1, fuel is injected with the help of a fuel injector specified as Fuel_inj in the schematic. The specified Air-Fuel-Ratio is set to 14.7 for this study. The flow splits into two branches as in the intake port of KTM390 engine and the air flows through the two inlet valves into the cylinder. The exhaust side is similarly modelled and a 300mm long exhaust runner is used to direct the exhaust gases to the ambient environment. The intake and exhaust, runners and ports are modelled using flow pipes with round cross sections. The diameter of the intake and exhaust runner is kept to be 43mm and 42mm respectively. For the sake of comparing performance between different valve profiles the intake and exhaust runner lengths don't need to be optimised.

In order to compare the performance, the input valve profiles are altered and the engine run is simulated in a range of 1500-10500 rpm. The key factors weighed in to compare the performance are sweep curves of Volumetric efficiency and Brake torque. Chart-2 shows exemplar data of varied lifts and the retarding of the profiles by 5 degrees. The overlap is changed by advancing and retarding the intake lift profile by 5 degrees.

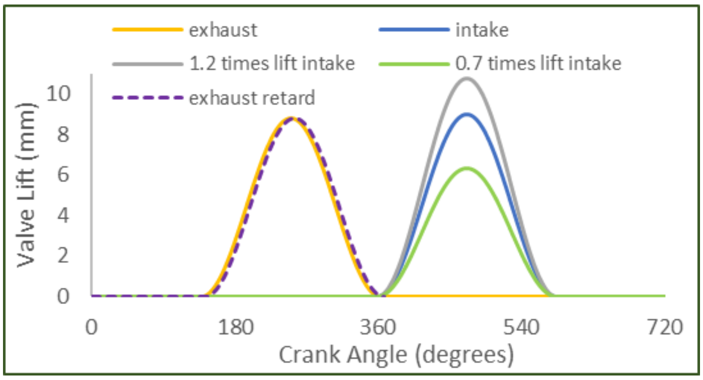

Chart -2: Valve Data Iterations

4. RESULTS AND ANALYSIS

4.1 Lift Iterations

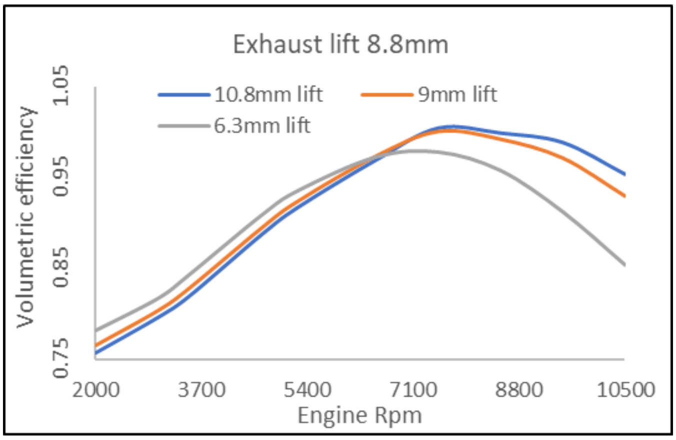

Chart -3: VE vs RPM (intake lifts are varied)

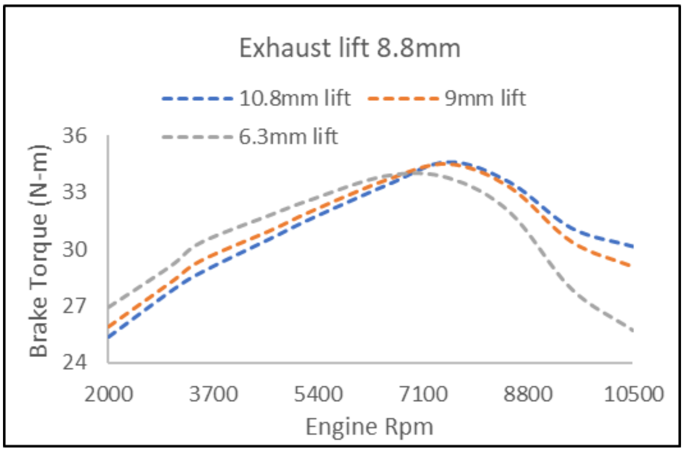

Chart -4: Brake Torque vs RPM (intake lifts are varied)

The curves shift to left as a whole, providing better VE (Volumetric Efficiency) at lower rpms even with lower lifts, with reduced peak torque for lower lifts. The VE and torque characteristics show that with an increased maximum lift in intake valves the higher rpm range performance increases while the lower range performance decreases. This could be explained as, at higher rpms the intake valve duration is less and with an increased lift more air-fuel charge is able to enter the combustion chamber in less time. Whereas, at lower speeds, the high lifts pose a problem, due to the fact that with more flow area, the air-fuel mix doesn't acquire sufficient speed and isn't able to form a homogenous mixture for combustion.

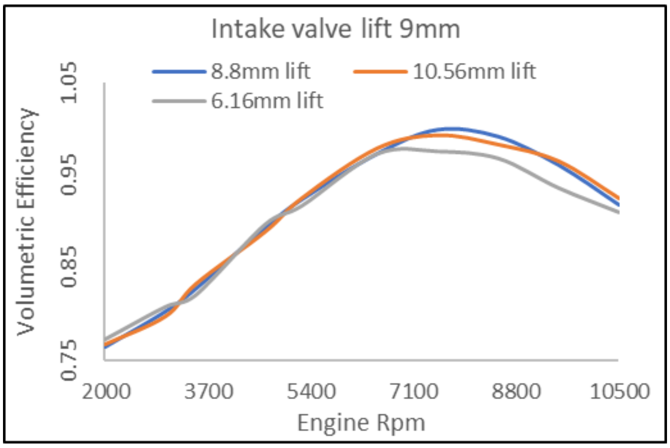

Chart -5: VE vs RPM (exhaust lifts are varied)

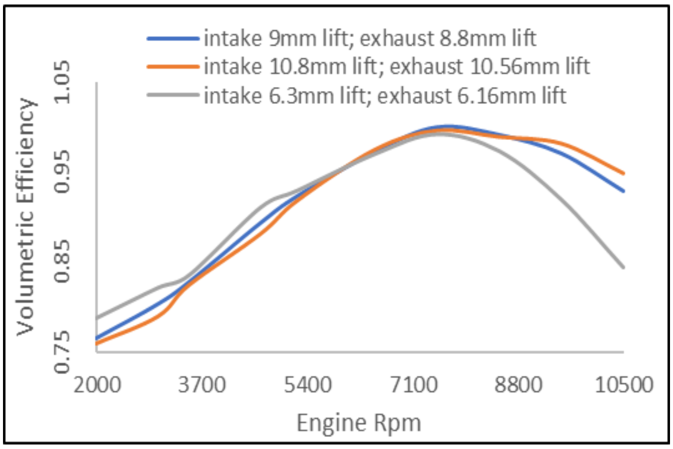

Chart -7: VE vs RPM

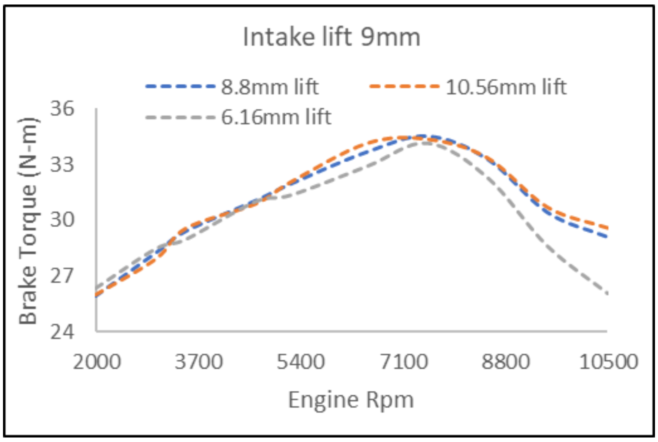

Chart -6: Brake Torque vs RPM (exhaust lifts are varied)

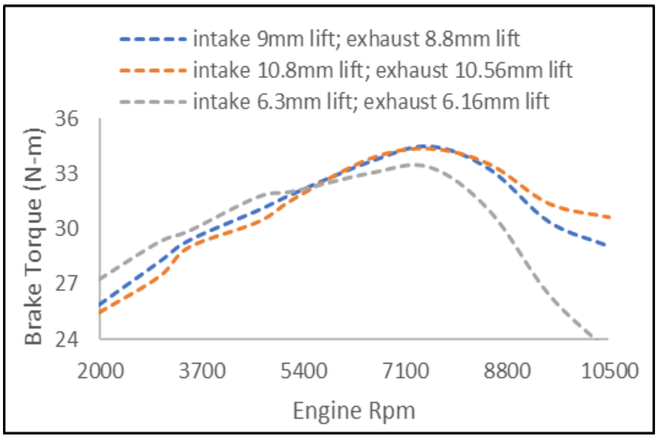

Chart -8: Brake Torque vs RPM

For engine speeds above 5000 rpm lower exhaust valve lifts seem to decrease the torque output. Since at higher engine speeds the exhaust gases are restricted due to less area available to flow through and a part of the burnt gases remain in the cylinder, this reduces the torque output. At lower engine speeds there isn't any noticeable difference in performance parameters. The torque has improved by 11-12% for 10500 rpm on increasing the exhaust valve lift by 4.4mm.

With a decrease in both the intake and exhaust valve lifts the higher and mid-range torque decreases whereas the low-end torque is increased. With low lift profiles of the valves, the airflow is severely hindered at higher rpms, hence the engine isn't able to breathe properly, and the volumetric efficiency is reduced severely. The low-end torque benefits from low lifts as lower lifts result in a higher velocity of the intake charge past the valves, improving fuel mixing and hence combustion. On comparing the torque output for low lifts vs high lifts for 10500 rpm, the torque has improved by about 30%.

4.2 Timing Iterations

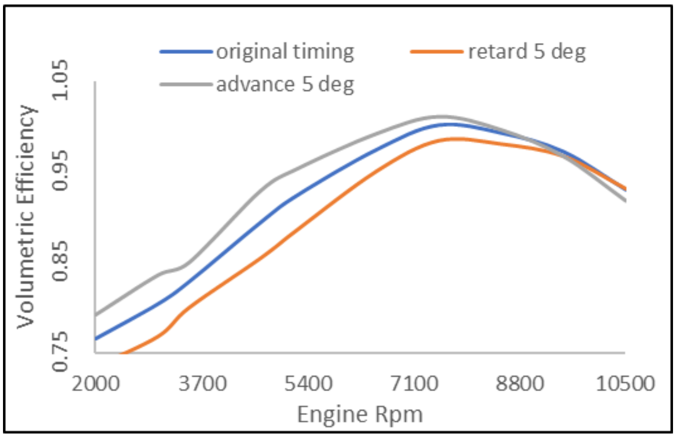

Chart -9: VE vs RPM

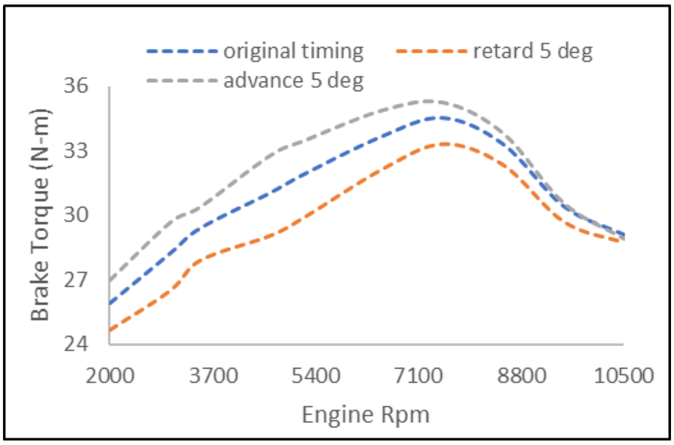

Chart -10: Brake Torque vs RPM

The data achieved shows that with advancing the original timing by 5 degrees the torque and VE characteristics improve, while retarding the events reduce the same. Also, the effects are more dominant in the 2000- 9000 rpm range. The peak torque has improved by 4% on advancing the timing. Although all valve events occur earlier, the greatest impact of advancing the valve profiles is to close the intake valve sooner. This means that a greater volume of air-fuel mix gets trapped and can be compressed before being ignited this has the effect of creating more torque, but too much advance can result in knocking at lower engine speeds due to the increased pressure.

4.3 Overlap Iterations

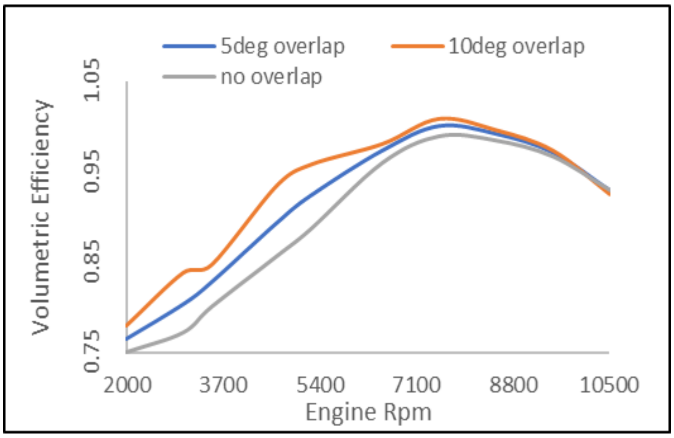

Chart -11: VE vs RPM

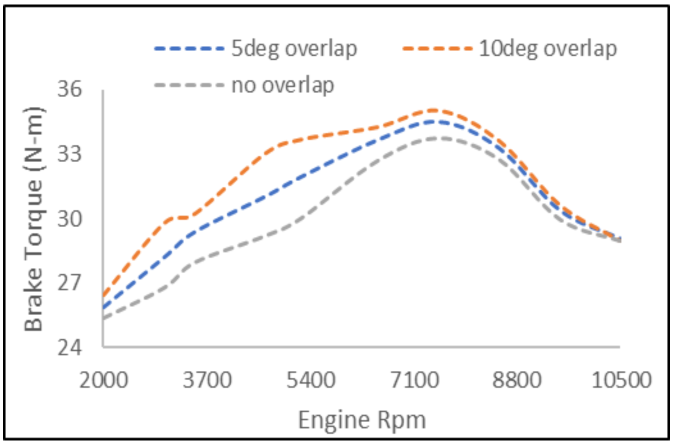

Chart -10: Brake Torque vs RPM

The VE and torque data achieved by iterating the overlap shows that by increasing the overlap the performance increases. Generally, a given amount of overlap tends to be ideal for specific engine speeds, as seen here an increase from 5 to 10 degrees greatly enhances torque in the 4500-6500rpm range, while at higher rpms the effect seems to be less dominant. The increased overlap helps in better scavenging of exhaust gases from the combustion chamber as the fresh intake forces them out through the exhaust valve. With low overlap, some of the exhaust gases remain inside the combustion chamber. These gases are at a higher temperature when compared to the intake charge, hence are less dense and in turn, affect the volumetric efficiency of the engine in a negative way as seen in Chart-11. The peak torque has improved by 4% on increasing the overlap from 0 to 10 degrees.

5. CONCLUSIONS

The effects of intake and exhaust valve events, lifts and timing on performance of a single-cylinder engine are successfully studied, simulated, observed and analyzed.
It is observed that higher valve lifts could improve engine performance for higher rpm ranges, while low valve lifts could be beneficial for low operating speeds. Intake valve lift has much more dominant influence on the volumetric efficiency than exhaust valve lift.

Advancing the valve timings could significantly improve the VE characteristics but too much of an advance could cause engine knocking.

Increasing the overlap of intake and exhaust valves could benefit the VE and torque characteristics as this provides more scavenging effect, although too much of an overlap could result in over-scavenging and could affect the performance negatively.

Through the analysis above, effects of valve events, lifts and timing are studied, which could provide a theoretical basis for engine tests with variable cams.

REFERENCES

[1] https://discovery.ucl.ac.uk/id/eprint/1317999/1/312736.pdf

[2] https://www.austincc.edu/wkibbe/camtheory

[3] Siewert, Robert M. “How Individual Valve Timing Events Affect Exhaust Emissions.” SAE Transactions, vol. 80, 1971, pp. 2156–2174. JSTOR, www.jstor.org/stable/44651847. Accessed 30 Oct. 2020

[4] Asmus T.W. (1984) Effects of Valve Events on Engine Operation. In: Hilliard J.C., Springer G.S. (eds) Fuel Economy. Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-2277-9_4

[5] Li, Liguang, et al. “Effects of Intake Valve Closing Timing on Gasoline Engine Performance and Emissions.” SAE Transactions, vol. 110, 2001, pp. 2270–2276. JSTOR, www.jstor.org/stable/44724482. Accessed 10 Nov. 2020

[6] Khudhur, S. H., Saleh, A. M., & Chaichan, M. T. (2015). The Effect of Variable Valve Timing on SIE Performance and Emissions. International Journal of Scientific & Engineering Research, 6(8), 173-179

[7] Gray, C. “A Review of Variable Engine Valve Timing.” SAE Transactions, vol. 97, 1988, pp. 631–641. JSTOR, www.jstor.org/stable/44547399. Accessed 7 Nov. 2020

[8] Sawant, Pauras & Bari, S.. (2018). Effects of Variable Intake Valve Timings and Valve Lift on the Performance and Fuel Efficiency of an Internal Combustion Engine. 10.4271/2018-01-0376.

[9] https://www.mechadyne-int.com/app/uploads/2015/05/the-impact-of-variable-valve-actuation-on-engine-performance-and-emissions.pdf

[10] "Performance Evaluation of Automotive Engines." ukdiss.com. 11 2018. All Answers Ltd. 11 2020 <https://ukdiss.com/examples/performance-evaluation-automotive-engines.php?vref=1>.

[11] Ghazi Mir Saied, SA, Jazayeri, SA, & Shamekhi, AH. "Modeling of Variable Intake Valve Timing in SI Engine." Proceedings of the ASME 2006 Internal Combustion Engine Division Spring Technical Conference. ASME 2006 Internal Combustion Engine Division Spring Technical Conference (ICES2006). Aachen, Germany. May 7–10, 2006. pp. 789-803. ASME. https://doi.org/10.1115/ICES2006-1411

[12] Yin, S.: Volumetric efficiency modeling of a four stroke IC engine. Thesis, Colorado State University (2017)

[13] KTM 390 Engine homologation data, Federation of Motor Sports Club of India, 213MC002 Homologation Form

[14] KTM. (2016). Owner's manual. Available: http://www.ktmshop.se/documents/29660a4bab78e43834a5cd62155a 8d05.pdf

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