ENGINE OPTIMIZATION BY USING VARIABLE VALVE TIMING SYSTEM AT LOW ENGINE REVOLUTION

Ainul Aniyah Sabaruddin, Surjatin Wiriadidjaja, Azmin Shakrine Mohd Rafie, Fairuz I. Romli and Harijono Djojodihardjo
Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
E-Mail: ainulaniyah@gmail.com

ABSTRACT

Engine optimization is one of the most cost-effective methods in reducing emissions and fuel consumption. In the theory, the maximum overlap would be needed between the intake valves and the exhaust valves opening whenever a common internal-combustion engine is running at high revolution per minute (RPM). At lower RPM, however, as the engine is run at lighter load, maximum overlaps may be useful as a means to lessen the fuel consumptions and emissions. The timing of air intake and exhaust valves are usually determined by the shapes and the phase angles of the camshaft. To optimize the air breathing, an engine would require different valve timings at different speeds. As the revolution speed increases, the duration of the intake and exhaust valves opening would decrease, thus less amount of fresh air may enter the combustion chambers, while complete exhaust gas cannot exit the combustion chamber in time. Therefore, varying the intake timing of an engine could help to produce more power and, if applied to smaller and lighter engine, it could result in a lower fuel consumption as well. This particular investigation has been conducted through simulations and complemented by experimental works. It has been realized in this study that optimization of an engine together with implementation of variable valve timing was able to generate similar power with an increase in volumetric efficiency, while it is obtained with a slightly lower fuel consumption. As reported by many researchers, the variable valve timing method has been indeed proven to deliver better fuel economy, less emissions, but higher torque under any operating condition.

Keywords: exhaust gas recirculation, valve overlapping, variable valve timing, engine optimization.

INTRODUCTION

Improvements of the performance of piston engines are continually investigated, so that it consumes less fuel while its impact on the greenhouse emissions is reduced. Among many possibilities for achieving the above objectives, there are development works carried out by car manufacturers and research organizations on different areas such as vehicle dynamics, weight reduction and engine management systems, though most of the emission and fuel consumption reduction is seen to be obtained only through increasing the efficiency of power train systems. One of the effective strategies to improve the engine efficiency is the engine downsizing [1-3].

In engine downsizing, the reduction of the engine's displacement will make an engine to operate at a higher load, thus increasing the mechanical and brake thermal efficiency, which will also reduce fuel consumption by limiting the pumping and friction losses. This will in turn lower the heat transfer energy due to the decreased total surface area [3-5]. In this particular study, the size of the investigated engine has been reduced from 10.04 cu. in. to 8.49 cu. in. while still maintaining a compression ratio of 9. Based on previous research work on engine downsizing for example in [6], some improvements must have been achieved, i.e. 74% improvement in torque, 102% improvement in power and 24% reduction in the brake specific fuel consumption (BSFC).

The variable valve timing (VVT) that was first proposed in 1880[7] has been proved to be a very effective methods in improving engine performance until today. The variable valve timing system may be classified into 3 different basic kinds that are based on their working principles, i.e. the variable phase timing, the variable cam profile, and the full flexible mechanism.

The VVT system controls the opening and closing time of intake valves according to different working conditions of the engine to improve its performance and fuel economy. In other words, a VVT system would improve the brake torque, deliver better power and reduce exhaust emissions in piston engines [8-10]. Numerous VVT mechanisms have been proposed and some of these have been implemented and demonstrated in engines. Most of the VVT implementation in automotive engines may be categorized into two modes of operations, low and high speed operations [11-14].

An important valve timing characteristic is called the overlap. An overlap is the period in the gas exchange event during which both inlet and exhaust valves are open at the same time. So far, the VVT system has been proved in producing an improved fuel economy, less emissions and better torque under any operating condition.

METHODOLOGY

Experimental work

The study started with an experimental test of a normal four stroke engine (EX17D). The EX17D is an air cooled single cylinder, four stroke engine manufactured by SUBARU. The tests were performed on the engine test bed TH-03 (Figure-1) that was supplied by SOLUTION ENGINEERING. This test has been conducted to see if the engine EX17D performance matches the power curve as it was claimed by the manufacturer, so that it can be used as reference for further investigation. Table-1 shows the general configuration of the used EX17D engine.

Once the experimental test were completed, the study then proceed with engine simulation try out to come out with an engine profile configuration that could match the power curve.

Figure-1. Engine test bed TH-03.

Table-1. General EX17D configuration.

EX17D Configuration	
Bore (inches)	2.613
Stroke (inches)	1.872
Compression (CR)	9
Displacement (cubic inches)	10.4
Other specification	Single cylinder, Air cooled, 4-cycle, Petrol powered

Simulation works

The simulation works implemented in this study have been based on the two available, commercial software:

1. PRO ENGINE ANALYZER [15] and
2. DYNOMATION-5 [15].

Simulation with PRO engine analyzer

The basic version runs simulations for gasoline and alcohol in normally aspirated mode or with turbocharged, supercharged, or nitrous options. It uses wave tuning algorithms for volumetric efficiency prediction that includes spark settings and detonation simulation. More than 70 engine specifications can be input to describe your proposed engine to the program. From this the simulation delivers up to 23 data outputs per RPM and over 18 special calculations, such as displacement and dynamic compression ratios. The program estimates a cylinder head flow curve that generated from a percentage-based of “flow efficiency” or optional input from the user. The program includes utility calculation screens that help you model compression ratios and other auxiliary calculations needed to support the simulator. It plots torque and horsepower per RPM graphically with up to seven overlays for run-to-run comparisons. From input or selected cam data it shows valve lift per crankshaft degree to help you evaluate cam profiles. An optimize feature of this simulations automatically chooses the best port or runner size or length for best peak torque and horsepower or average torque and horsepower.

Simulation with Dynomation-5

Dynomation-5 is a simulator based on extensive wave action simulation. It ability to allow user to experience the engine combination to view, analyze, and understand the powerful wave dynamics that influence induction and exhaust flow. It could provide evaluation of specific intake runner lengths, section widths, port taper angles, header tubing and collector dimensions, and how they affect valve engine and the operational gas dynamics in the engine. The combustion chamber selector provides nine different combustion geometries based on chamber shape, burn rate characteristics and chamber timing requirements based on gasoline.

Based on EX17D configuration size, a new proposed resized cylinder (Table-2) is created smaller than the first. Below are the information used to conduct the simulation for the study. Based on the results obtained by these two simulation programme, this study then proceed with the programme that gave the best desired output.

Table-2. Comparison to the new proposed engine size.

	EX17D Configuration	Resized Configuration
Bore (inches)	2.613	2.600
Stroke (inches)	1.872	1.600
Compression (CR)	9	9
Displacement (cubic inches)	10.4	8.49

To implement the variable valve techniques on the new proposed resized engine, two different sets of cams are used. One is use from the start of the engine, second is activated when the engine’s RPM reaches 2500 and above. The used cam configuration in this study for the resized engine are as below

VOL. 10, NO. 20, NOVEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-3. Cam configuration.

Bore:	2.6 inches	Compression ratio:		9
Stroke:	1.6 inches	Displacement:		8.49 cubic inches
	Intake		Exhaust	
Centerline	115	ATDC	65	BTDC
Open	30	BTDC	30	BBDC
Close	80	ABDC	80	ATDC
Duration	290		290	
Total cam advance :		25 retard		
Lobe Separation :		90		

Table-3 refers to cam configuration used for normal sized (EX17D based) and the proposed smaller sized engine for below 2500RPM. As the RPM increases, the cam configuration will change to another as stated in Table-4. Duration stated in the tables are the difference between the closing and opening angles. This is the number of degrees the valves are "off their seats". Duration is usually expressed in crankshaft degrees.

Table-4. Cam configuration at 2500 RPM.

Bore:	2.6 inches	Compression ratio:		9
Stroke:	1.6 inches	Displacement:		8.49 cubic inches
	Intake		Exhaust	
Centerline	95	ATDC	125	BTDC
Open	50	BTDC	90	BBDC
Close	60	ABDC	20	ATDC
Duration	290		290	
Total cam advance :		15 adv		
Lobe Separation :		110		

RESULTS AND DISCUSSIONS

Based on the conducted experiment, the power output is the compared to the power curve given by the company. Based on the specifications given this engine were supposed to be able to run at 4000 RPM speed maximum. Unfortunately, during the experiment, the highest RPM obtainable were 3700 RPM.

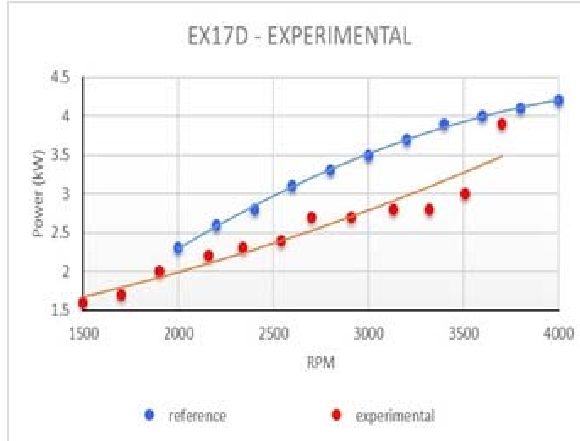

Figure-2. Power output of experimental versus reference.

From the experiment, the results (Figure-2) obtained were a lot lower than the given power curve. This is normally due to several power loss that happen as the engine works and also regard to the age of the engine will indirectly effect the performance of the engine. Figure-3 shows the overal results comparing the simulation done in try to match the power curve given by the company. Based on the results obtained, the study found that Pro Analyzer has given a better desired power curve compared to the Dynomatiom. Study the proceed with implementation of downsizing an engine with VVT by using Pro Analyzer.

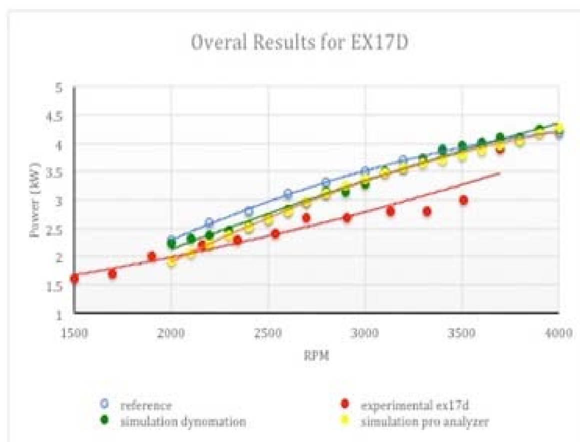

Figure-3. Overall comparison of the power output of EX17D

Based on the results obtained, this study will then proceed for the variable valve timing settings implementation with the Pro Analyzer data as it give the best and closest results to the power curve provided by the company.

Implying variable valve timing for low speed engine

Based on the results, at 2500RPM the power were increased up to 15.64% and 20.38% at 4000RPM

ARPN Journal of Engineering and Applied Sciences

(Figure-4) whereas the volumetric efficiency of the engine increased about 15% (Figure-5).

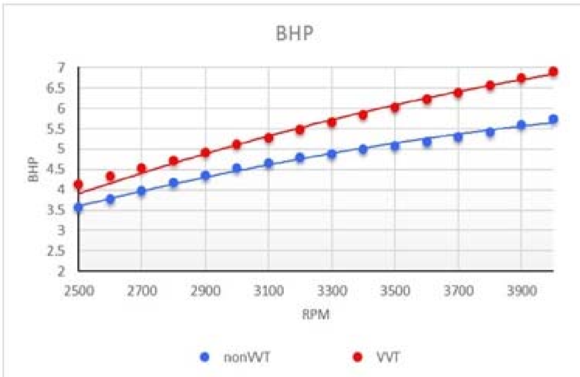

Figure-4. Brake horsepower versus RPM.

However, unfortunately, the fuel flow of the engine increased as well. With 16.01% increased at 4000 RPM (Figure-6), this is something that is not desirable. This however is possibly due to that, it is said before that variable valve timing may increase power but not necessarily lower fuel consumption especially for low speed engine.

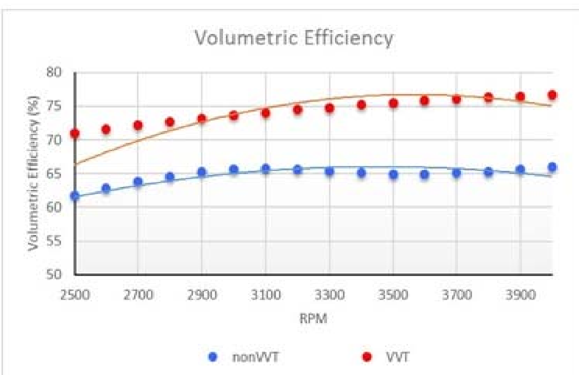

Figure-5. The volumetric efficiency of the engine.

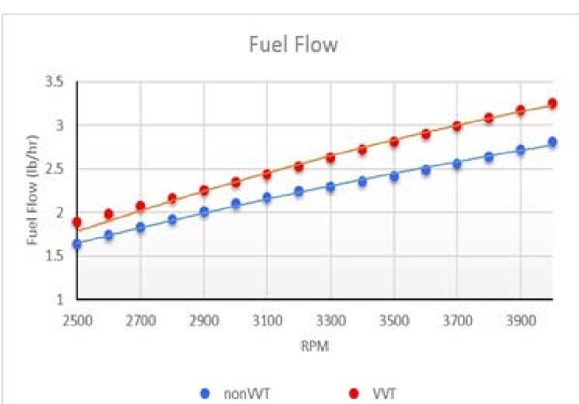

Figure-6. Fuel flow versus RPM.

Reducing the displacement of the engine with variable valve timing.

With the same configuration, the engine sized is then changed from 10.04 cubic inches of displacement to 8.49 cubic inches (Bore : 2.6 inches, stroke : 1.6 inches) of displacement hoping that with this slightly smaller size perhaps this configuration are able to give out similar output as EX17D but with any enhancement.

From the stimulated test, in term of the power output (Figure-7) for a smaller size engine it started out with 20% less power at 2000RPM but however it started to surpass the bigger size's power at 3700RPM and by the end of 4000RPM the engine is able to give out about 1.2% more or less the same power as the older sized engine. Even with roughly similar power output throughout the whole run, the smaller engine does consume slight lower fuel and it save out about 2% throughout the whole run at every RPM.

As for the volumetric efficiency of the engine (Figure-8) starting at 2500 RPM the efficiency increased up to 12% overall. As for the fuel consumption, the results shows (Figure-9) that the smaller engine indeed used slight lower amount of fuel and this can be regard as a possible savings over time.

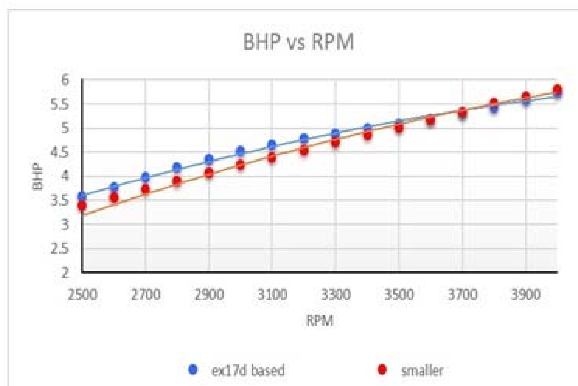

Figure-7. BHP comparison of EX17D based engine to a smaller one.

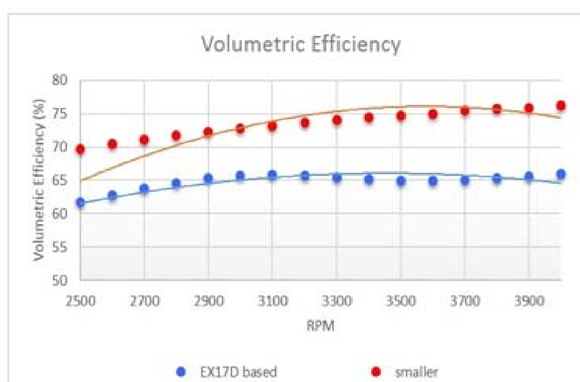

Figure-8. Volumetric efficiency comparison of EX17D based engine to a smaller one.

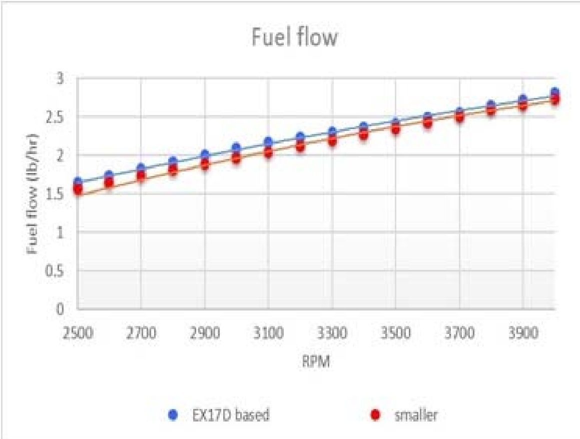

Figure-9. Fuel flow comparison of EX17D based engine to a smaller one.

CONCLUSIONS

In most cases, engine downsizing is mostly done with supercharging or turbocharging, but in recent automobiles engine developments, the most used engines nowadays do have smaller sizes but yet able to deliver higher power by means of different kind of techniques. Based on results obtained in this investigation, it is believed that this could contribute to a lighter weight of engines with a slightly lesser use of fuel consumption. Efficiency of an engine would be increased though higher power production if compared with those of common engines of similar sizes. Smaller and lighter engines that are able to deliver high end power as if it were bigger than its sizes, would surely give a lot of benefits. Not to mention the pollutant emission that is released by these optimized engines would also be less in accordance with the less fuel consumption thus helping to contribute to a greener environment.

NOMENCLATURE

ABDC	After Bottom Dead Centre
ATDC	After Top Dead Centre
BBDC	Before Bottom Dead Centre
BSFC	Brake specific fuel consumption
BTDC	Before Top Dead Centre
cu. in.	cubic inches
RPM	Revolution per minute
VVT	Variable Valve Timing

REFERENCES

[1] T. Lake, J. Stokes, R. Murphy, R. Osborne and A. Schamel. 2004. “Turbocharging Concepts for Downsized DI Gasoline Engines,” SAE International, no. 2004- 01-0036.

[2] J. Taylor, N. Fraser, R. Dingelstadt and H. Hoffman. 2011. “Benefits of Late Inlet Valve Timing Strategies Afforded Through the Use of Intake Cam In Cam Applied to a Gasoline Turbocharged Downsized Engine,” SAE International, no. 2011-01-0360.

[3] J. M. Zaccardi, A. Pagot, F. Vangraefschepe, C. Dognin and S. Mokhtari. 2009. “Optimal Design for a Highly Downsized Gasoline Engine,” SAE International, no. 2009-01-1794.

[4] B. Lecointe and G. Monnier. 2003. “Downsizing a Gasoline Engine Using Turbocharging with Direct Injection,” SAE International, no. 2003-01-0542.

[5] C. Stan, A. Stanciu, R. Troeger, L. Martorana, C. Tarantino, M. Antonelli and R. Lensi. 2003. “Direct Injection Concept as a Support of Engine Down-Sizing,” SAE International, no. 2003-01-0541.

[6] Atul Gupta, Jonathan Saul and Ramzy G. Abdel-Gayed. 2012. “Downsizing of A Naturally Aspirated Engine to Turbocharged Gasoline Direct Injection Variable Valve Timing Engine", International Journal of Engineering and Applied Sciences, 2012, ISSN2305-8269.

[7] Thomas Dresner and Phillp Barkan. "A Review And Classification Of Variable Valve Timing Mechanisms", SAE Paper 890674.

[8] Hong H., Partave-Patil G. B. and Gordon B. 2005. Review and Analysis of Variable Valve Timing Strategies-Eight was to Approach, Proceedings of the Institution of Mechanical Engineers, Part D, Journal of Automobile Engineering, Vol. 218, No. 10, pp. 1179-1200.

[9] Gölcü M., Sekmen Y., Erduranlı P. and Salman S. 2005. Artificial Neural Network Based Modeling of Variable Valve Timing in a Spark Ignition Engine, Applied Energy, Vol. 81, pp. 187-197

[10] Nagaya K., Kobayashi H. and Koike K. 2006. Valve Timing and Valve Lift Control Mechanism for Engines, Mechatronics, Vol. 16, No. 2, pp. 121-129.

[11] Kim D. S. and Cho Y. S. 2005. Effects of Cam Phase and Spark Retard to Increase Exhaust Gas Temperature in the Cold Start Period of an SI Engine, International Journal of Automotive Technology, Vol. 6, No. 6, pp. 585-590.

[12] Sellenau M., Kunz T., Sinnamon J. and Burkhard J. 2006. 2-step variable valve actuation: sytem optimization and integration on an SI engine, SAE Technical Paper, No: 2006-01-0040, 2006.

[13] Haugen D. J., Blackshear P. L., Pipho M. J. and Esler W. J. Modifications of a Quad 4 Engine to Permit Late Intake Valve Closure, SAE Paper, No: 92 I663.

[14] Kreuter P., Heuser P. and Schebitz M. Strategies to Improve SI-Engine Performance by Means of Variable Intake Valve Lift, Timing and Duration, SAE Paper, No: 920449.

[15] "Engine Simulation and Modeling Software Guide." N.p., 24 Jan. 2015. Web. 5 May 2015. <http://www.musclecardiy.com/performance/engine-simulation-modeling-software-guide/>.