MODELLING AND SIMULATION OF CYLINDER DEACTIVATION SYSTEM APPLIED TO PASSENGER VEHICLES

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This thesis is submitted as to fulfil the requirements for the award of the degree of Bachelor of Mechanical Engineering (Automotive)

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JUNE 2015

AUTHOR DECLARATION

"I hereby declare that the work in this thesis is my own except for summaries and quotations which have been duly acknowledged."

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Dedicated to

My Beloved Mom and Dad

ACKNOWLEDGEMENT

The writer expresses his highest gratitude to the supervisor of this project, Dr. Ahmad Kamal bin Mat Yamin for his contributions and support throughout the research was carried out. Without him, the project cannot be done any better and smoother.

Recognition is also given to other lecturers who help the writer along the way during the methodology process which helped the writer achieved the simulation results for this research.

Finally, the writer wants to express his deepest sincere appreciation to all his colleagues that assisted him not only with the research but also other side projects that were ongoing when the thesis was being done.

ABSTRACT

Cylinder Deactivation System, CDS or generally referred to as variable displacement is a technology developed that can permit the total engine displacement to vary by shutting down one or more cylinders to increase overall fuel efficiency. The primary study of this research was to simulate how CDS would perform when applied to passenger vehicles by using MATLAB Simulink. Vehicle modelling using MATLAB Simulink is a process of creating a reference tool to the real world counterpart and using existing parameters to obtain results via simulation. The difficulty in this case study was formulating a functioning model for simulation purposes and determining the CDS performance under any number of working cylinders. Objectives of the research were formulating the vehicle longitudinal model, predicting CDS performance when applied to passenger vehicles, and proposing a control strategy for the CDS when used. The methods used were first deriving the necessary equations based on vehicle dynamics, creating the vehicle longitudinal model using the developed equations, and finally simulate it to get the theoretical results. The results gathered from this research were based on the output value of the model which was the vehicle speed.

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LIST OF SYMBOLS

F_X	=	Force acting on the vehicle
μ	=	Pacejka 'magic' model constant
F_Z	=	Normal force
F_{X_T}	=	Total force acting on the vehicle
$\dot{V}$	=	Rate of velocity
g	=	Gravitational acceleration
m	=	Mass of vehicle
F_d	=	Drag force
L	=	Wheelbase
B	=	Length from rear axle to center of gravity
C	=	Length from front axle to center of gravity
H	=	Height of center of gravity
F_a	=	Aerodynamic force
F_r	=	Resistance force
C_r	=	Rolling resistance coefficient
A	=	Frontal area of the vehicle
C_d	=	Aerodynamic drag coefficient
ρ	=	Density of air
λ	=	Slip ratio
$\dot{\omega}_i$	=	Wheel dynamic
τ_e	=	Engine torque delivered to each wheel
τ_b	=	Brake torque applied to each wheel
τ_r	=	Reaction torque on each wheel due to the tyre tractive force
$\tau_{d_i(\omega_i)}$	=	Viscous friction torque
ω	=	Wheel speed
C_f	=	Viscous friction coefficient

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Modern vehicle nowadays strive to achieve EEV status which abbreviates from Energy Efficient Vehicle. EEV is defined as vehicles that meet a set of define specification in terms of carbon emission level (g/km) and fuel consumption (l/100km) (source from Malaysian Automotive Institute, MAI). One strategy to reach the EEV requirement is by employing a fuel-efficient assist system. A lot of systems had been used in today's cars such as variable valve timing (VVT), cylinder deactivation system (CDS), active spoiler, start-stop and many more. In this research, most of the work will be based on the cylinder deactivation system since it is the most common fuel-efficient assist system applied to passenger vehicles.

Cylinder deactivation system, CDS or also commonly known by variable displacement is a technology developed that can allow the overall displacement engine to change by deactivating one or more cylinders to increase the overall fuel efficiency. This system is widely used in multi-cylinder internal combustion engines. Even though this application has been seen only recently, the technology was around for quite some time. The first being is the hit-and-miss engine where it was developed in the late 19^{th} century. It was a single cylinder stationary cylinder which had a centrifugal governor that cuts the cylinder out of the operation as long as the engine speed was operating above a set limit usually by holding the exhaust valve open. Current technology of CDS however uses the same principle but cuts off any of the working cylinders by switching cam positions to close the valves.

Due to the cause of decreasing the fuel consumption, it is important that CDS needs to be research much more prominently. Prior to this, CDS has only been used in vehicles with big engines such as V6's and V8's. However, the system now seems to be adapted into smaller engine such as the in-line 4-cylinder engines. This is because car manufacturers are opted for engine downsizing of engine to reduce carbon emissions, increasing fuel efficiency and also cut cost. The study about CDS is significant because this system has recurrent problem which is pumping losses when the cylinders in an engine are partially off.

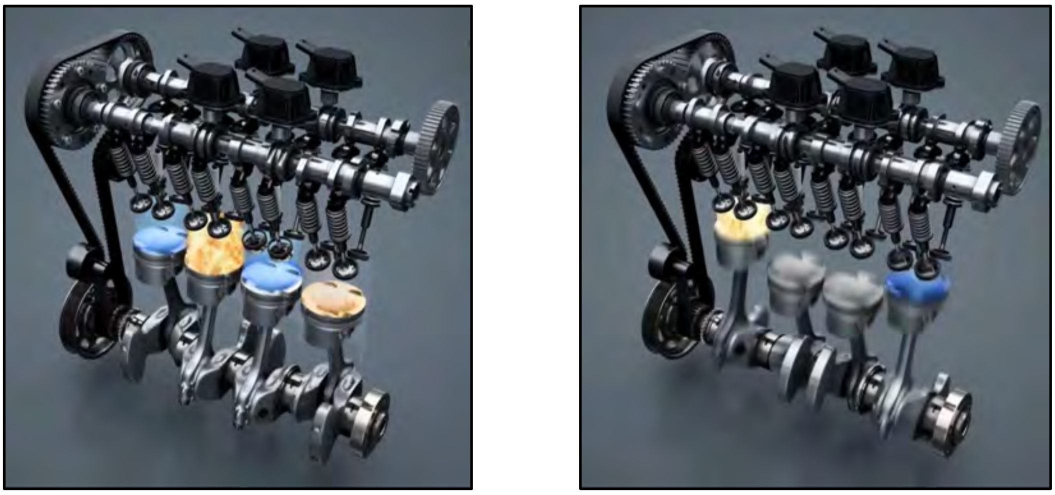

Figure 1.1 Volkswagen engine with Active Variable Displacement (ACT)

Table 1.1 EEV requirements for road vehicles

Segment	Description	Kerb Weight (KG)	Fuel Consumption (l/100km)
A	Micro Car	<800	4.5
	City Car	801 – 1000	5.0
B	Super Mini Car	1001 – 1250	6.0
C	Small Family Car	1251 – 1400	6.5
D	Large Family Car	1401 – 1550	7.0
	Compact Executive Car		
E	Executive Car	1550 – 1800	9.5
F	Luxury Car	1801 – 2050	11.0
J	Large 4x4	2051 – 2350	11.5
Others	Other	2351 – 2500	12.0

Table 1.2 EEV requirements for two wheelers

Engine Size (cc)	Fuel Consumption (l/100km)
50 – 100	2.0
101 – 150	2.2
151 – 200	2.5
201 – 250	3.0

Pumping losses has always been a major concern in CDS. This inefficiency occurs during light-load or part-load driving conditions where only a portion of the engine's total power is used. Throughout part-load driving, the throttle valve is nearly closed and this causes the engine to draw air into the cylinders with extra work hence inadvertently making pumping loss happens. One way overcome this is by decreasing the compression ratio which in return also reduces the pumping loss during part load. Another solution to counter this is by induce more air into the cylinders during light-load conditions

To decrease the compression ratio, we can take inspiration from the Atkinson Cycle which is commonly used in hybrid vehicles. The Atkinson Cycle consist of 5 strokes process which are intake, first compression, second compression, power and exhaust in a flowing order. What differentiates the Atkinson Cycle and the widely used Otto Cycle in automobiles is that during the first compression, the intake valve is kept open till the second compression stroke so that the air can be pushed out back into the intake manifold. This causes the compression ratio to decrease and also flow the air back into the other cylinders which needs more air thus decreases the pumping loss. Other ways to draw more air into the cylinder is by having a turbocharger or using a 4-2-1 exhaust manifold which can help engine breathing to be more efficient. Besides mechanical solutions, employing a control strategy into the engine process can also help improve the overall efficiency by controlling the valve timing or number of cylinder usage during part-load conditions.

Some of the solutions stated to counter the pumping loss have been applied in modern vehicles of today. The Atkinson Cycle as said is commonly used in hybrid vehicles because the electric motor can compensate the side effects when compression ratio is decrease. Even though pumping loss can be reduce when the compression ratio is decrease, the negative effect to that is producing less power output. Since hybrid cars have an electric motor to help increase the total output performance, the side effect can be countered. Turbocharging can be seen more and more in passenger vehicles nowadays due to output power it can produced even in small capacity engines. The prime example of this can be seen in Volkswagen engines with variable displacement technology where the turbo can help draw more air into the working cylinders.

1.1 PROBLEM STATEMENT

Cylinder Deactivation System, CDS currently is being adapted more regularly into smaller engines unlike before. This is to help increase the engine's maximum efficiency during part-load driving. Hence, the research challenge is on how to formulate a math model to generate a control strategy so that the number or functional cylinders during part or full load can be determined.

1.2 OBJECTIVES

1. To develop a vehicle longitudinal model.
2. To predict the performance of the cylinder deactivation system when applied to passenger vehicles.
3. To propose a control strategy when the cylinder deactivation system is used.

The aim of this research is to model and simulate the cylinder deactivation system when applied to passenger vehicles. The first objective is done so that a clear output data which is the vehicle speed can be generated from the model to predict the performance of CDS. The second objective is executed to determine how the cylinder deactivation system can affect the car performance by applying it to the vehicle longitudinal model. The third and final objective is done to find out the number of functioning cylinders required by the engine depending on the load required by the vehicle.

1.3 SCOPE OF STUDY

1. A compact city car (A-segment) with a kerb weight 801-1000kg will be used as the test subject for the research.
2. The input data that will be from the driving cycle.
3. A level road surface is one the parameters for the simulation test as the vehicle model will be drive forwards only with no cornering.

The data of this research is first followed up by the first objective. When the vehicle longitudinal model is complete, the simulation then can take place to generate the necessary data. The second outcome would be coming up with a control strategy. The analysis from the results can help to formulate the control strategy for the vehicle. The third result would be predicting the performance of the system when applied to passenger vehicles to observe how it would affect the engine efficiency.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Cylinder Deactivation System, CDS has prominently evolved throughout the years in automotive advancement. As stated before, it has been around since the 19^{th} century. The application of the systems varies depending on how the manufacturers intend on making it work in an internal combustion engine. However, the most significant similarities between all of them are that it depends on the speed of the moving vehicle. Hence, it is important to study existing similar CDS counterparts as well any other fuel-efficient assist system that have been applied to modern vehicles so that the modelling of vehicle longitudinal model can take place.

2.1 FUEL-EFFICIENT ASSIST SYSTEM RELATING TO SPEED

In this section of the report, information regarding fuel-efficient assist system applied to passenger vehicles will be explained. It is noted that the examples shown are systems that functions based on the vehicle motion speed. Even though the research will be based on CDS, other examples such as variable valve timing, start-stop system, driving mode change and active spoiler will be taken into consideration to help guide the modelling of the vehicle longitudinal model for simulation purposes.

2.1.1 Variable displacement

Variable displacement can be considered the main example for cylinder deactivation system due to its working mechanism. It operates by changing the engine output capacity which is done usually by switching off one or more cylinders which in return change the total displacement of an engine to give out better fuel efficiency.[1] This system is widely used in vehicle which has multi-cylinder engines. Car manufacturers have been applying this technology since 2005 but the idea have been long existed prior before that.

During low-load conditions, the system is applied so that it can increase the fuel efficiency and also reduced the gas emission in the process. Normally, the driver only uses one third of an engine's total power output in this kind of situations. During which, the throttle valve is nearly shut. However, the engines still requires some work to draw in air into the engine. Due to this, pumping loss will occur.

There are even in some cases where a car with higher capacity engine needs to pull in a lot of air at light load conditions which can cause the pressure in the cylinder at top dead center (TDC) to be roughly half that of a typical common smaller in-line engines. Thus, result in lower fuel efficiency.

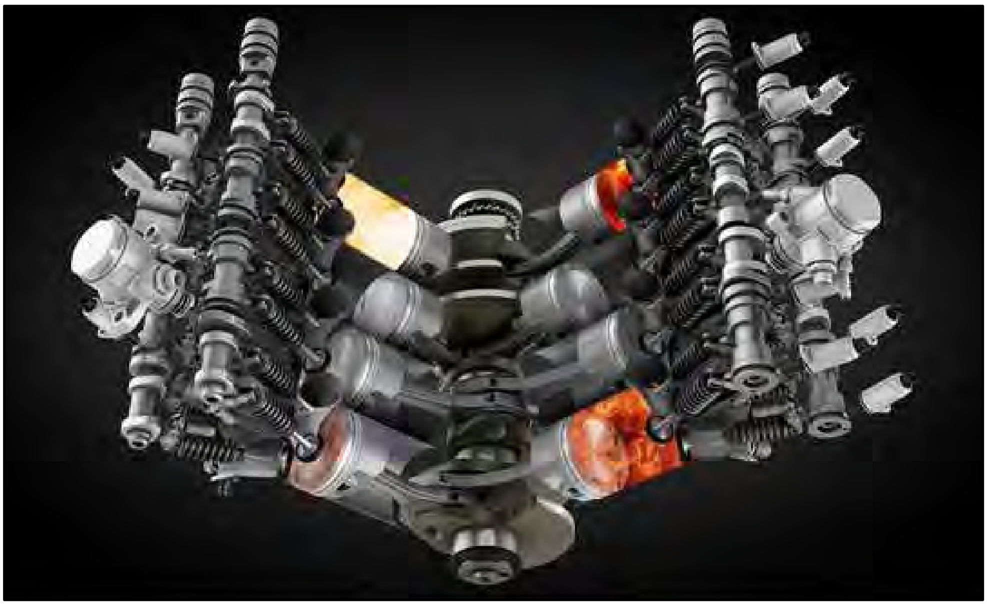

Figure 2.1 Bentley Continetal V8 engine with variable displacement system

With variable displacement system functioning at a lower driving load, only fewer cylinders will be required to draw air into the engine which can help to raise the air pressure. In absence of this system, fuel is unnecessarily pumped into each cylinder for combustion process even when no additional power is required during part-load situations. Therefore, by altering the total engine working cylinders to half, the amount of fuel consumed in theory can be reduced to half as well. The fuel consumption figures is said to be decrease to almost 25% when the engine displacement is cut down during this operation.[3]

The total displacement of an engine can be decreased by shutting down or deactivating a cylinder with maintaining the intake and exhaust valves of a certain cylinder to be closed.[2] By doing so, the exhaust gases are unable to escape at the end of a cycle will be compressed when the piston moves upwards and will be pushed downwards when it moves downwards. This phenomenon can be called as the “air spring” effect. The decompression and compression of the trapped exhaust gases will have an overall effect of where no extra load will be put on the engine.

Latest development concerning variable displacement can be seen from a fuel cut delivery system where it is also use by the engine management system to turn off any of the cylinders. The change between full cylinder and deactivated cylinder operations is also help by improving the ignition and can as well as using an electronic throttle position. This type of fuel-efficient assist system is usually used in engines with large capacity displacement which are not designed to be efficient during low load conditions. For example, a V12 engine can have half of its cylinders shut off but the disadvantages in that cause the system to have unbalanced cooling and increase in vibration.

2.1.2 Variable valve timing

Variable valve timing or better known as VVT is a system that can adjust the engine’s valve lifting timing and it is normally done to increase the performance of the vehicle while raising the fuel economy and decreasing emissions. This system is rapidly being used with a combination of variable valve lift systems. Mechanical devices or electro-hydraulic and camless system are one of the few ways in which the process can be attained. Concerning about the strict regulations about emissions being enforced, many automobile manufacturers prefers the VVT system in their engines. For a case of a two-stroke engine, a power valve system is used to get the performance of a VVT system.

In an internal combustion engine, the flow of the intake and exhaust gasses into and out of the cylinders respectively are controlled with the used of valves. The lift, timing, and duration of these valves events will have implication on the output performance of the engine. If an engine does not use variable valve timing, the valve timing will be equal for all the engine speed and conditions, thus certain compromises are necessary.[4] An engine that is equipped with this system however is free from this constraint which allows the performance to become better with the engine operating range. The valves are usually actuated by camshafts where the cam lifts the valve open for a certain period of time throughout intake and exhaust stroke. The timing of the valves for opening and closing is also essential as the camshaft is driven by the crankshaft through chains, gear, or timing belts.

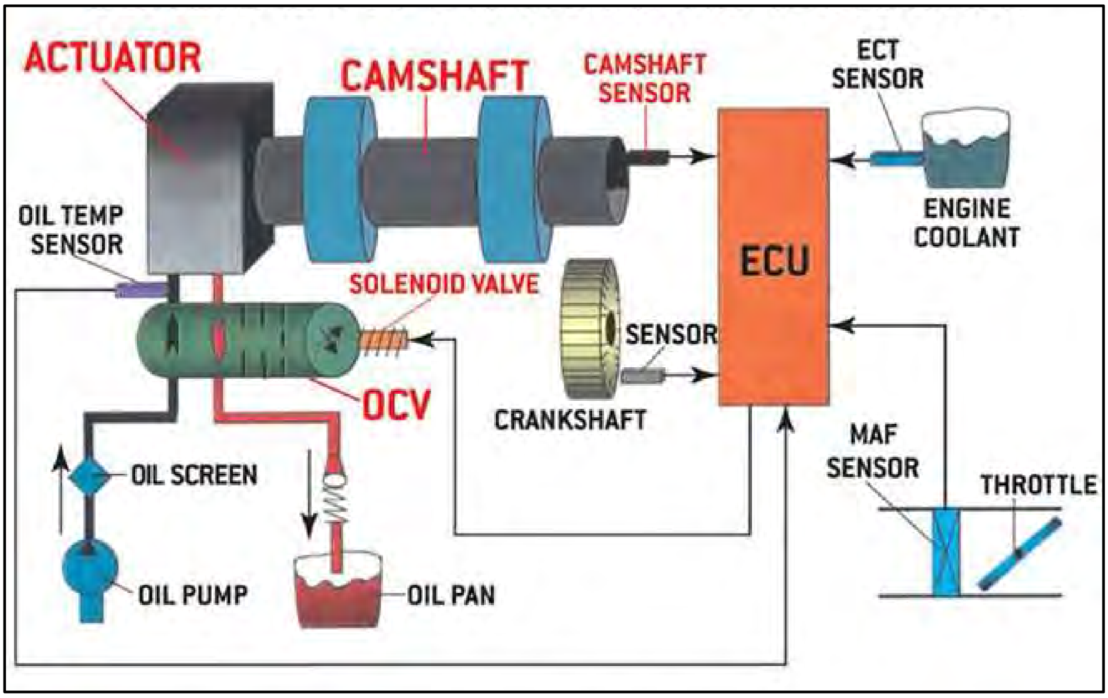

Figure 2.2 General VVT system configuration

The engine when operating at high speeds requires large amount of air to get the best possible output. However, the intake valves may close before sufficient air has gone into the cylinder which can results in low output performance. If the camshaft keeps the valves open for a longer period of time, problems will start to happen when the engine is at lower speeds because it can cause unfinished combustion to take place and the fuel to exit the engine since the valves are still open. This in result will induce a reduction in engine performance and also an increase in emissions.

2.1.3 Start-stop system

A car that has start-stop or stop-start system can automatically shuts down and restart the internal combustion engine so that the amount of time the engine spends during idling will be decrease and hence increasing the fuel efficiency as well as reducing emissions. This technology is very useful for road vehicles in cities or urban areas where most of the time is spend on queuing at traffic light junctions or during rush hour where cars constantly come to a halt. This system is predominantly introduced in hybrid electric vehicles but also has been seen used by car that is powered by a normal combustion engine. The fuel efficiency is said to be raised from 5% to 10% for non-electric vehicles or micro-hybrids.

Figure 2.3 Typical Mercedes Benz button to activate start-stop system