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Engine Performance Analysis of Cylinder Deactivation System

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Abstract

In this paper, the main research area is focus on the investigation of cylinder deactivation (CDA) technology on common engine part load conditions within common Malaysian driving condition. CDA mostly being applied on multi cylinders engines. It has the advantage in improving fuel consumption by reducing pumping losses at part load engine conditions. Here, the application of CDA on 1.6 liter four cylinders gasoline engine is studied. One-dimensional (1-D) engine modeling is performed to compare the performance between CDA and normal modes. Also, the predicted in-cylinder combustion diagrams as well as pumping losses are presented. The study shows that the CDA mode has very significant effect on the engine performance. Pumping losses is found to be reduced, thus improving fuel consumption and engine thermal efficiency.

***Keyword**: CDA, engine performance, engine model, GT-Power, pumping loss*

1. Introduction

Increasing oil prices and emission legislation have forced automotive company to investigate new methods and technologies to reduce the harmful effect produced from the motor vehicle, particularly CO_2. In order to meet consumer and legislation requirements, big investments on key technology strategies have been made to ensure fuel consumption is reduced.

Many technologies have been developed to improve engine efficiency and reduce the fuel consumption. These technologies include turbocharger, supercharger, engine downsizing, variable valve timing, gasoline direct injection, and cylinder deactivation (Hirschfelder, 2002; Taylor et al., 2012). Cylinder deactivation (CDA) is one of the alternatives in reducing the engine fuel consumption. The reduction of fuel consumption will affect the ability of the engine to run at part load operation (Vendan, Sathish, & Sathishkumar, 2009). In order to understand the detail behaviour of CDA system on engine performance, engine simulation tool is the best method to analyse the suitable parameters and conditions before applying the cylinder deactivation technique inside the real engine.

2. Cylinder Deactivation (CDA)

Recent technologies for gasoline engines include lean combustion technologies including direct injection and homogenous charged compression ignition, the optimizing intake and exhaust valve timing and valve lift and the cylinder deactivation system (CDA) has been practised to improve the engine efficiency. Among of these, the cylinder deactivation system, which is a promising method to reduce fuel consumption, has been applied to mass production vehicle by automobile manufactures since 1980’s. However production applications during that particular year have been very limited due to mechanical failure. In addition, most attempts with cylinder deactivation techniques previously are done with 6 or more cylinders due to the engine stability and vibration control. After the failure of MMC’s 1.4-liter engine, there is not many studies have been conducted for the inline series 4-cylinders naturally aspirated (NA). However, the evolving of advanced controller integrated with engine management system is believed to bring this technology for the NA engine become relevant in the future.

Cylinder deactivation is achieved by deactivating (closing) the intake and exhaust valves and by shutting down the injector as well as the ignition signal to the unfired cylinders. As a result, the enclosed air works like a pneumatic spring which is periodically compressed and decompressed without overall pumping work (Boretti & Scalzo, 2013; Flierl, Lauer, Breuer, & Hannibal, 2012). Ideally, the compression and decompression of the trapped gases have an equalising effect, which supposedly received no extra load on the engine. Most of the current cylinder deactivation systems are used mechanical actuation valve train, where a hydraulic/mechanical control is used to prevent the cam lobes from actuating the valves. Generally, the principle of cylinder deactivation is always tried to shut off the valves at the deactivated cylinders, the only different is the mechanism.

Although the CDA has numerous benefits, it also has significant drawbacks. The largest drawback is substantial increase in the amount of testing data required in the initial development stage. Much iteration required in order to identify the most significant region for deactivation zone. Hence, the authors chose simulation as an approach to investigate the benefits of CDA on a 1.6L naturally aspirated spark ignition (SI) engines. By using engine modelling, the amount of testing required is reduced due to the most of testing is done virtually through simulation study. To establish a robust engine model requires a broad range of experimental data. Therefore, actual engine experiment on bench needed in order to collect all the ECU parameters to be inserted as an input for engine model.

This study focuses on the analysis of engine performance for naturally aspirated SI engines featuring CDA by simulation approaches. The ability of simulation tool, so called GT-POWER will be exploited. The simulation will shows the benefit of cylinder deactivation technique in spark ignition engine to the extent of fuel consumption improvement in common engine operating condition.

3. Common Engine Operating Condition

The study on common engine load condition with Malaysian City Driving has been done by (Zahari, Abas, Mat Arishad, Zainal Abidin, & Muhamad Said, 2013). Here, a normal passenger car has been droved within the Klang Valley offering different level of traffic conditions such as congested traffic, city cruising, and highway cruising which represents the Malaysian City driving to accumulate the load conditions. Besides the routes, the city driving test simulates actual consumers driving whereby other factors such as ambient temperature, road-load values and air-conditioning turned on were included.

Based on this study, the recommended range of accelerator pedal position and brake torque during city driving are reported (Figure 1 and Figure 2). These are the condition that recommended for applying the CDA technique in reducing the fuel consumption without compromise the power and torque. The torque depends on the driver demand that will cause launching, drivability and engine response.

These recommended engine operating conditions are very useful for investigation study of engine with CDA technology. Engine performance simulation activity is carried out to determine the differences between normal mode and CDA mode at this common operating condition.

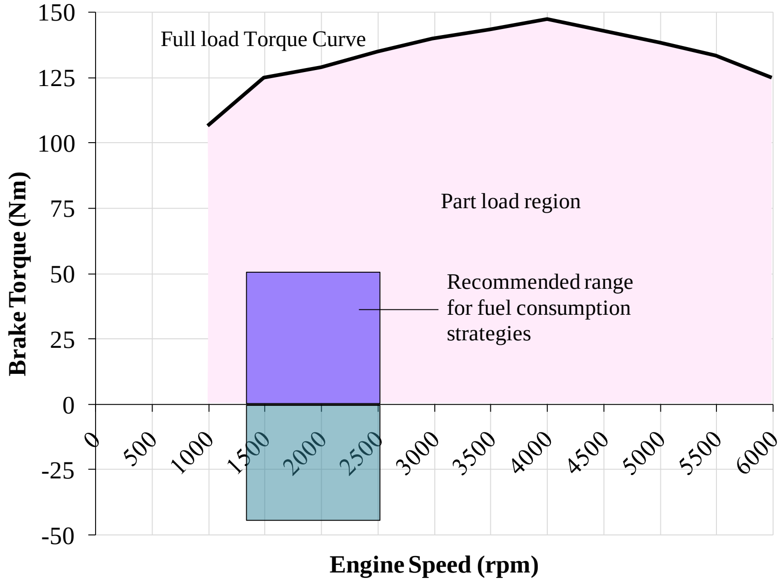

Figure 1. Recommended brake torque range for CDA (Zahari, et al., 2013)

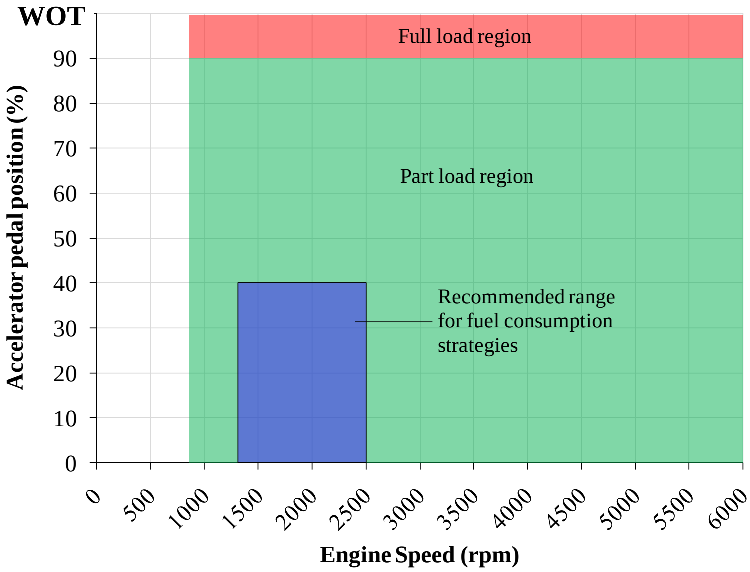

Figure 2. Recommended accelerator pedal position rage (Zahari, et al., 2013)

4. Engine Modeling for CDA application

In this study, a one dimensional (1D) fluid dynamic computational simulation is used to assess the CDA engine performances. Here, software called GT-Power is used to analyze an engine model of natural aspirated, 1.6 L, spark-ignition engine. This engine model has been developed and correlated to the actual data at normal mode operating condition (Muhamad Said, Abdul Aziz, Abdul Latiff, Mahmoudzadeh Andwari, & Mohamed Soid, 2014). The technical specifications of the engine are listed in Table 1.

Table 1. Engine technical specifications

Layout	In-line 4 cylinder
Valve mechanism	16-Valve DOHC
Total displacement (cc)	1597
Bore (mm)	76
Stroke (mm)	88
Max. Power	93 kW @ 6500 rpm
Max. Torque	150 Nm @ 4500 rpm

The correlated engine model reported by Muhamad Said et al. (2014) has been modified and use as a prediction tool to analyze the application of CDA mode on engine performance (Figure 3). Here, the model was set to run using 2-cylinder mode which is with CDA mode. Cylinder number 2 and 3 were deactivated by defining zero lift for intake and exhaust valves. Combustion model for these both cylinders were ignored and fuel to air ratio are set to 0. The engine only operates with cylinder number 1 and 4. The CDA mode use similar intake and exhaust valves timing and lift and also having similar air fuel ratio (AFR) as normal mode.

Both modes are operated at part load engine conditions. They operated at engine speed of 1500 to 4000 rpm, with brake mean effective pressure (BMEP) of 3 bar. This operating condition has been selected based on the common driving condition in Malaysia as described in section 3 above. The detail works of this Malaysian driving activities have been reported by (Abas, Salim, Martinez-Botas, & Rajoo, 2014; Zahari, et al., 2013).

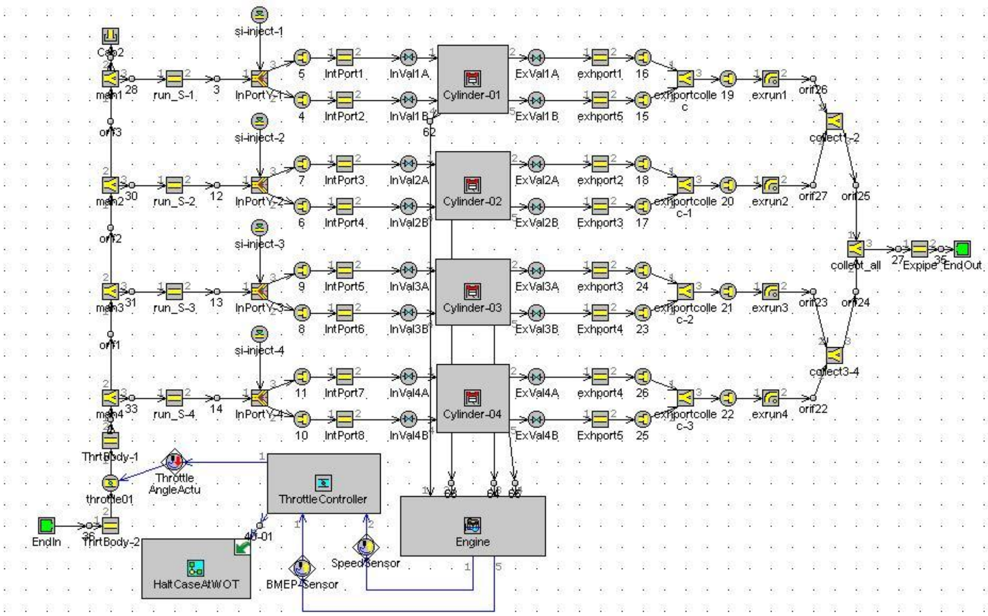

Figure 3. Engine model for CDA mode

5. Results and Discussions

A simulation analysis is done on the CDA mode engine model and the normal mode engine. The results of the simulation analysis are discussed by comparing both type of modes. The normal mode engine model consists of 4 cylinders engine operation while the deactivation mode engine model operates with 2 cylinders engine only. The simulation is done for the engine model that runs at of 1500RPM to 4000RPM. This speed is selected to achieve the findings of different operating condition for the deactivation mode engine and normal mode engine.

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For normal naturally aspirated spark ignition engine, the maximum values of BMEP are in the range of 8.5 bar to 10.5 bar (Muhamad Said, et al., 2014). This is the range for a full load operation of normal engine. The project is focus on the cylinder deactivation engine behaviours during part load operation. Thus, for this analysis, the target BMEP for the engine is set to 3 bar.

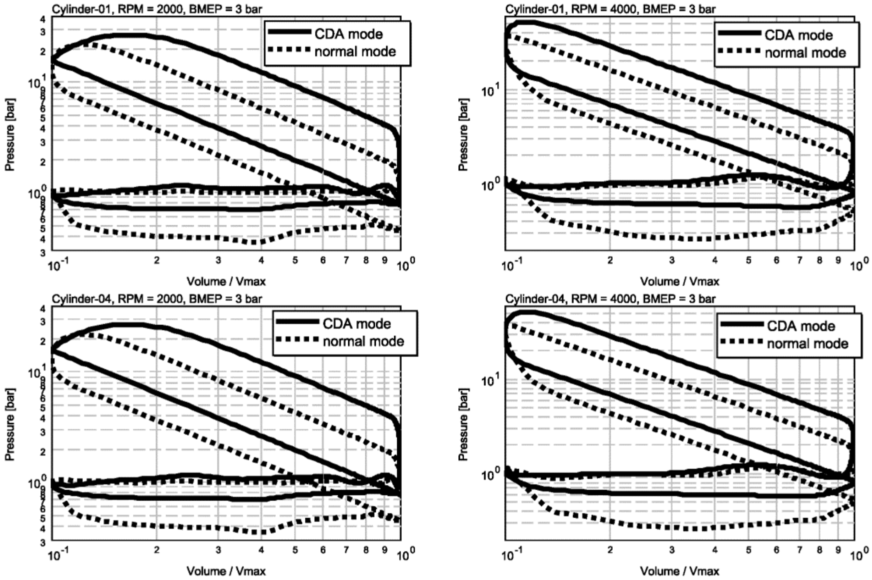

Figure 4. Comparison of P-V diagram between deactivation mode engine and normal mode engine for cylinder-01 and cylinder-04

Figure 4 shows the predicted results of Log Pressure against Log Volume for cylinder-01 and cylinder-04. The results of simulation for cylinder-01 is same as cylinder-04 at both engine speed for the comparison of the pumping loss. This type of graph indicates the phasing pressure inside the cylinder of the engine. The upper pumping represent the compression and power stroke while lower pumping represent the intake and exhaust stroke. Moreover, the area of the graph for intake and exhaust line shows the negative work that is known as pumping loss.

The differences between the areas of the pumping loop between the two curves are magnified by the log scale. According to the comparison between CDA mode and normal mode engine model, the engine that operates in CDA mode has smaller pumping loss compare to the engine that operates at normal mode for both engine speed. The low pumping loss indicates that less negative pumping work is done by the engine. This show that CDA engine produce less negative pumping work for the operation compare to normal engine.

For normal mode, it seems that the results for the pumping loss obtain for this analysis is high. This is due to low engine load that is set for this analysis which 3 bar of target BMEP. This analysis requires the engine to run in a condition of less than wide open throttle (WOT). The partially opening throttle will restricts the amount of intake air to enter the engine cylinder which cause pressure drop for incoming air. This influences the increase in pumping loss inside the cylinder engine.

Figure 5 shows the brake thermal efficiency at various engine speeds for the engine load of 3 bar. It is found that the CDA mode recorded higher brake efficiency compare to normal mode. This means that CDA mode operates more efficient than normal mode due to the lower pumping loss inside the engine cylinder.

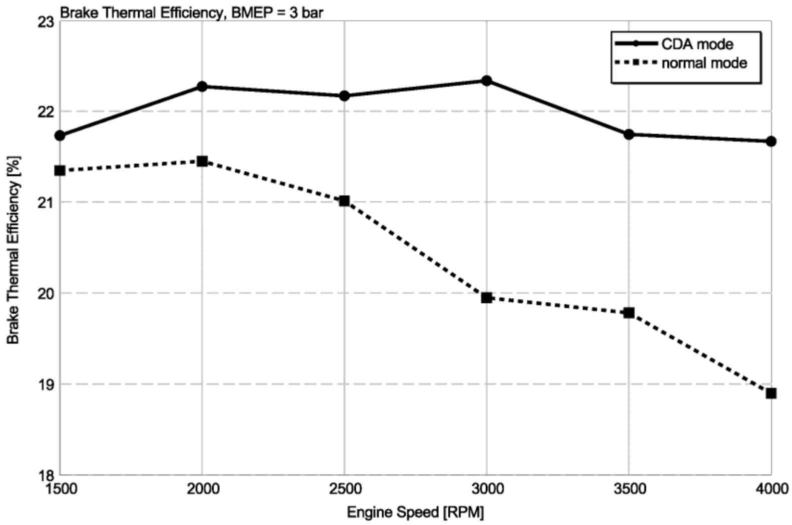

Figure 5. The graph of brake efficiency against engine speed for CDA mode and normal mode

Other than that, higher brake thermal efficiency is also due to low mass of fuel flow rate used for the engine to operate. According to (Boretti & Scalzo, 2013) research on piston and valve deactivation for improved part load performances of internal combustion engines, the brake thermal efficiency correspond to the fuel consumption of the engine. Less fuel consumption will promote high engine performance due to saving of fuel. Lower fuel consumption is also contributed by the advantage of CDA in reducing pumping loss (Figure 6).

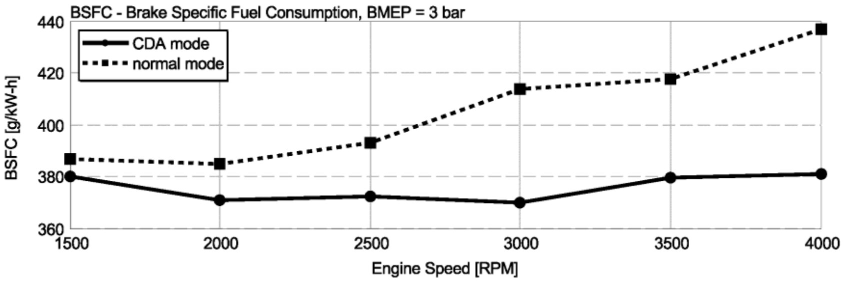

Figure 6. Comparison of CDA mode and normal mode in term of BSFC.

6. Conclusion

Computer simulation techniques are applied to obtain better understanding in term of cylinder deactivation technology on engine performance. The investigation of CDA technique on spark ignition engine has been performed. The CDA engine has been successfully constructed based on the previous correlated spark ignition engine model. The simulation of CDA engine has been performed on the BMEP of 3 bar for engine condition at 1500RPM to 4000RPM. The simulation is done by comparing the engine performance between CDA engine and normal engine. Lower BSFC and higher brake thermal efficiency were recorded during the CDA mode. These improvements are due to the lower pumping loss.

Acknowledgments

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