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A Design of Novel Valve Train System for Cylinder Deactivation in SI Engines

Ly Vinh Dat.[1, *], Le Nam Anh[1], Tran Anh Tuan[2]

[1]Faculty of Vehicle and Energy Engineering, Ho Chi Minh City University of Technology and Education, Ho Chi Minh city, Viet Nam
[2]Faculty of Automotive, Tran Dai Nghia University, Ho Chi Minh City, Viet Nam

Email address:
datlv@hcmute.edu.vn (L. V. Dat.)

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Abstract: Cylinder deactivation is a potential method in improving efficiency and fuel consumption in SI engines. The optimal strategies about driving torque at different operating conditions can improve the fuel consumption in engine. Many recent researches have demonstrated that the cylinder deactivation modes can be successfully applied in improving engine efficiency at different engine loads. Different cylinder deactivation strategies have been applied for full range of engine load. However, deactivating cylinder in engine requires complex structure of valve train system. The study proposes a design valve train, which is improved from the conventional valve train system in an inline SI engine with 4 cylinders, to control for deactivating cylinder. The study results show that the proposed design, which differs to the existing valve train design, can deactivate one or two cylinders modes that depend on part load or medium load in vehicle. In addition, the novel design with simple structure and easy control can fully satisfy the controlling of cylinder deactivation strategies in SI engines.

Keywords: Cylinder deactivation (CDA), Variable valve timing (VVT), Valve train system, Engine efficiency, Fuel consumption

1. Introduction

CDA, which is also known as cylinder deactivation, is applied in SI engines by shutting off all valves and cutting off the fuel supply to deactivated cylinders for all cycles simultaneously as shown in Fig. 1. The aim is to reduce the stroke volume, instead of decreasing the mixture charge, by controlling the intake valve. Additionally, these deactivated cylinders act as an "air spring", which performs compression and expansion cycles periodically. Hence, CDA also is considered an effective method to significantly reduce pumping losses at part load conditions.

Figure 1. *Cylinder deactivation for a 6 cylinder engine [1]*

The benefits of CDA in reducing fuel consumption and emission at low engine loads have been studied. The experimental results of an inline 4-cylinder engine with 2 deactivated cylinders (50% CDA) can improve efficiency by about 20% and decrease HC-emission about 10-40% for low load conditions [2]. The flexible use of an electromagnetic valve train system to operate at various modes, such as those with 2, 3, or 4 valves, as well as the use of cylinder deactivation modes in an engine is mentioned in [3]. Fuel consumption can be improved over a wide range of operating conditions. Two cylinders have been deactivated with different firing degree intervals in an I4 2.0 L camless engine. Experimental results have shown that the improvement of fuel consumption is about 11.25% for cylinder deactivation mode at low engine load and speed.

Similarly, Vendan in [4] mention reducing fuel consumption in a 4-cylinder SI engine by cylinder deactivation technique. Experimental results show that the average 22.71% reduction in fuel consumption for two-cylinder mode (50% CDA) compared to four-cylinder. A 6-cylinder engine with CDA technique has been described by [5]. The number of deactivated cylinders was determined according to the required driving torque. This research has shown that three-cylinder mode (50% CDA) can obtain the best fuel efficiency at cruising speeds under low loads. The four-cylinder mode (66% CDA) is applied for higher loads and normal engine operation is for driving under full loads. Many methods were listed in improving SI engine efficiency at part load [6-7]. The researchers found that combining various methods improved engine efficiency and proposed the use of both VVT and CDA techniques concurrently, a combination which can improve fuel economy by about 14-16%.

In this paper, a valve train system, which is improved the conventional valve train system, is redesigned to control the cylinder deactivation in SI engines. The intake valve in cylinder will be opened in all cycles for deactivating cylinder. The new valve train system will perform the one-cylinder and two-cylinder deactivation modes in this work. The novel design is characterized by a simple structure, easy control and can fully meet the strategies of cylinder deactivation control. Besides, the study also optimizes the CDA strategies for engine load ranges

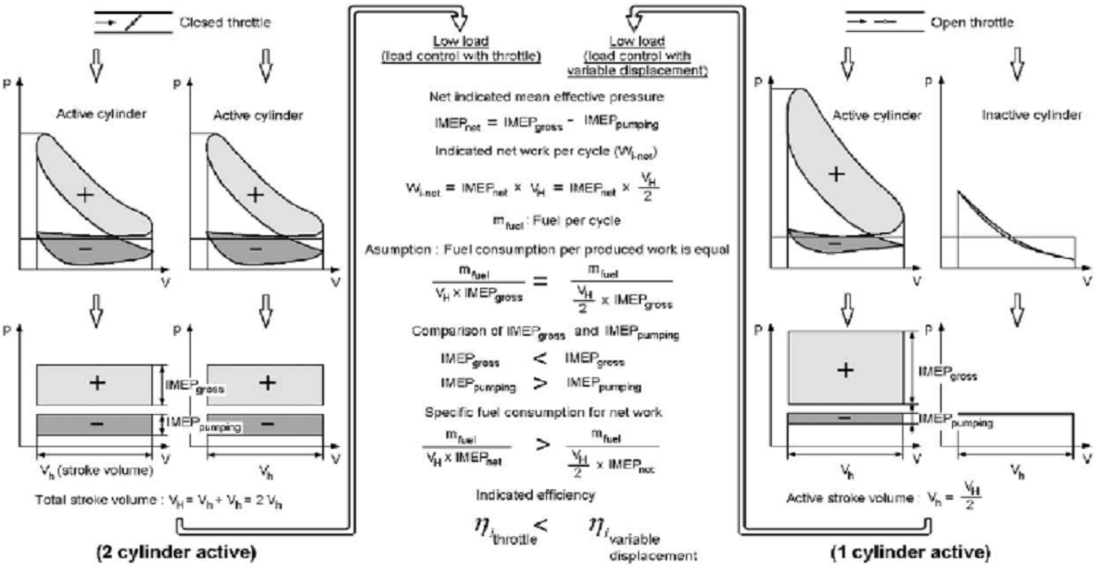

Figure 2. *Schematic comparison of a 2 cylinder SI engine p–V diagrams and corresponding efficiency without and with variable displacement at part load [6].*

2. Design of valve train system for cylinder deactivation

2.1. Cylinder Deactivation

Cylinder deactivation has some advantages for SI engines that have the large displacement volume. However, in the recent year, this method is applied in SI engines, which have small cylinder volume, in improvement the fuel consumption for part loads. An engine with the cylinder deactivation technology is the simple keeping the intake or exhaust valves closed through all cycles, at the same time, the ignition and fuel delivered to the cylinder deactivations are cut - off by blocking the injector and ignition signals. By closing valves in the cylinder is used as an "air spring". This air spring performs a periodical compression and expansion cycle, which eliminates the pumping losses (apart from blow-by).

The cylinder deactivation brings some benefits for engine efficiency by decreasing the pumping loses at part load. A schematic example is given for a SI engine with 2 cylinders in Fig 2. Throttle valve is nearly closed and pumping losses are high in 2 cylinders active mode at part load. Whereas, tthrottle valve is more opened to get the same power and pumping losses are lower in one-cylinder active and one-cylinder deactive mode. This results in improving the engine efficiency and fuel consumption for cylinder deactivation.

2.2. Cylinder Deactivation Control Mechanism

The study has been performed in Hyundai engine G4EK with conventional valve train system as shown in Fig 3. Engine uses signle over head camshaft (SOHC) system, which has 12 valves for 4 cylinders, to control intake and exhaust valve timings.

Figure 3. *The conventional valve train system in Hyundai engine G4EK*

The research has improved the conventional valve train by adding some parts to carry out the cylinder deactivation as shown in Fig 4. The secondary rocker arm and secondary camshaft will actuate the intake valve at opening position for the cylinders which need to cut off. This mechanism system, which differs from the existing cylinder deactivation control design, alway keeps the intake valve at opening position when we need to deactive the cylinder along with the cutting off the ignition and fuel to the cylinder deactivation. This results in the decreasing pumping loseses due to the intake, compression cycles.

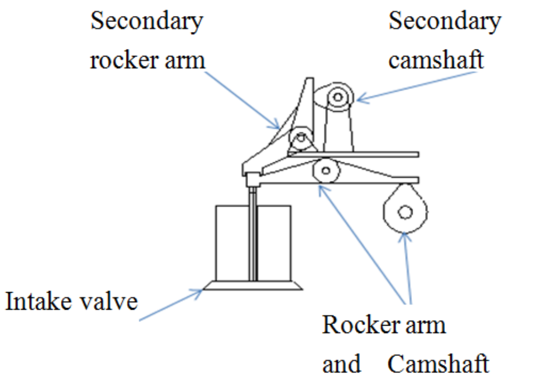

Figure 4. *Intake valve control mechanism for cylinder deactivation.*

When electrical motor rotates, it will drive the secondary camshaft rotate, the cam lobe actuates the secondary rocker arm that presses the intake valve at opening position. The maximum distance opening intake valve is about 0.2 ÷0.5 mm. When the intake valve open makes cylinder will be deactived.

The study has been performed in Hyundai engine with 4 cylinders. The cylinder deactivation must be accorded with the driving torque that denpends on engine load. Therefore, the maximum cylinder numbers can be cut off in engine about 3 cylinders. The valve train mechanism for deactivating is outlined in Fig 5.

The mechanism can control to cut off one, two or three cylinders that depends on the driving torque at various operating loads. The camshaft includes two parts: the camshaft with two cam lobes for deactivating cylinder #1 and #2, and camshaft with one cam lobe for controlling cylinder # 3. Both camshafts are engaged and disengaged which is controlled by motor B. Motor B can control the splined joint that slips for engaging or disengaging the camshafts. Motor A rotates the camshaft to press the intake valve at opening position. Therefore, the cylinder deactivation mechanism can cut off one-cylinder, two-cylinder or three-cylinder modes by combining motor A and motor B.

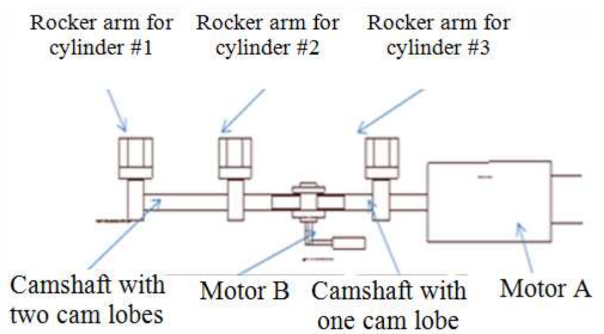

Figure 5. *The outline of cylinder deactivation mechanism*

The splined joint and fork, which control slip joint, can connect and disconnect 2 parts of camshaft as shown in Fig 6. The fork is controlled by the motor B (see in Fig 6).

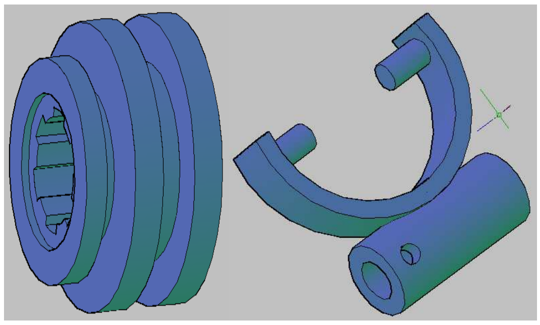

Figure 6. *The splined joint and controlled fork*

We have proposed a mechanism that can control cylinder deactivation with different strategies: one-cylinder deactivation, two-cylinder deactivation and three-cylinder deactivation states, these modes depend on the driving torque in vehicle. However, there-cylinder deactivation mode is only excuted for very low loads that can't meet for the driving torque when vehicle run on the street. Therefore, in study we have proposed and manufactured a cylinder deactivation control mechanism that can cut off one or two-cylinder deactivation as shown in Fig 7. This design has mechanism, structure and control that are similar to the above mechanism as show in Fig 8.

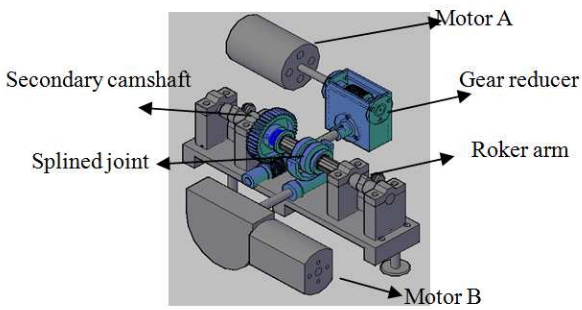

Figure 7. *The cylinder deactivation control mechanism diagram*

The mechanism for controlling cylinder deactivation is applied on Hyundai Accent engine with 4 cylinders. By adding the mechanism for deactivating cylinder and keeps the conventional valve train system for cotrolling valve timing.

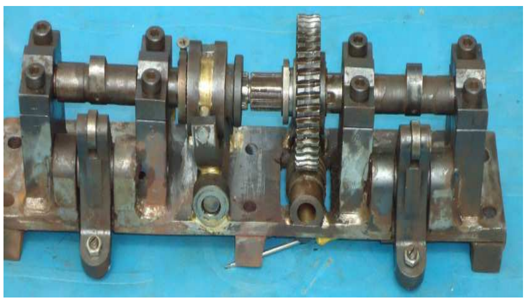

Figure 8. *The mechanism for controlling cylinder deactivation.*

The purpose of research designs a mechanism that can cut off the cylinders. Depend on engine loads, mechanism will control one-cylinder mode or two-cylinder deactivation mode. One -cylinder deactivation mode will be peformed for medium engine load. Two-cylinder deactivation mode for low engine load. This improves fuel consumption in SI engines. To demostrate this mechanism, a model is shown in Fig 7. Motor A rotates the secondary camshaft to press the intake valve at opening position. Motor B controls the splined joint for deactivating one-cylinder or two-cylinder dectivation modes. The mechanism for controlling cylinder deactivation is installed in Hyundai engine as shown in Fig 9.

Figure 9. *The mechanism installed in Hyundai engine*

The novel valve train system can control and cut off cylinder easily which is not affect to the controlling of valve timing in engine.

2.3 The Optimal CDA Strategies for Load Engine Ranges

In this research, the two-cylinder deactivation and one-cylinder deactivation modes have been investigated at the low and medium engine loads. At high engine loads, the use of CDA causes some disadvantages for the engine performance and fuel consumption. Correspondingly, the effects of CDA are not examined for the high loads. Additionally, the use of more than two deactivated cylinders cannot satisfy the driving torque at all of operation conditions in the engine. Therefore, this application will not be investigated in this approach, either.

The two-cylinder deactivation mode generates the maximum torque at 5.2 bar BMEP, whereas the one-cylinder deactivation mode produces the maximum torque at 8.6 bar BMEP. Therefore, the two-cylinder deactivation mode is examined only at the low engine loads, while the one-cylinder deactivation mode is examined from the low to medium load. Fig 10 shows the effects of CDA on the fuel consumption at full range of engine load. The simulation results conclude that the use of two-cylinder deactivation is the most optimal solution for the low engine loads. Similarly, the one-cylinder deactivation mode is an optimal selection for the medium loads. And finally, normal engine is best used for the high engine loads.

By using the two-cylinder deactivation mode, the engine efficiency can be considerably improved at part load because each activating cylinder in the mode has to be operated at higher IMEP. This leads to a significant improvement for the pumping losses in this mode. The one-cylinder deactivation mode is selected for improving the engine efficiency at the medium load as the simulation results. At these loads, the use of one-cylinder deactivation mode satisfies the driving torque and it can use higher IMEP in each engine and therefore these lead to the improving engine efficiency for vehicle. On the contrary, cylinder deactivation will not be used in engine at high engine loads because CDA cannot satisfy the output power and the improving engine efficiency is thermodynamically limited at full loads. Accordingly, these causes will lead to some disadvantages for the fuel consumption at that load.

As the results shown in Fig 10, a SI engine will control valve open so that it operates at the two-cylinder deactivation mode to reach the optimal fuel consumption at low engine load. The one-cylinder deactivation mode will be controlled to result in some benefits about fuel economy at medium engine load. Finally, SI engines will operate at normal engine mode to obtain the fuel economy and satisfy the engine power at full engine load.

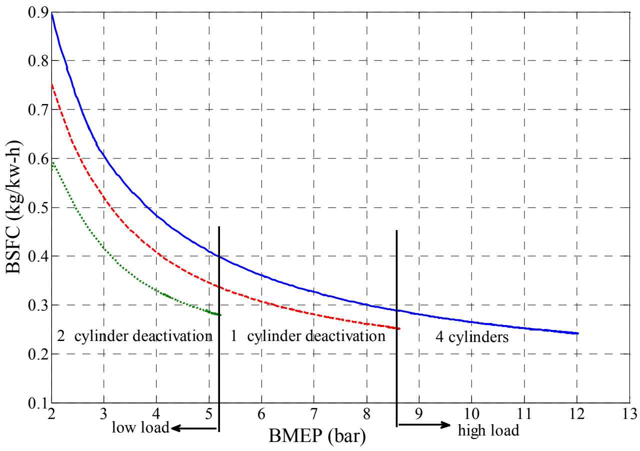

Figure 10. *The effects of cylinder deactivation at entire load ranges*

3. Conclusion

A new valve train system, which differs to the existing design, has been proposed to control cylinder deactivation in SI engines. The novel design is characterized by a simple structure, easy control and can fully meet the strategies of cylinder deactivation control. The use of CDA results in several benefits in improving SI engine efficiency at low engine load. Improvements resulting from CDA will degrade as engine load increases. The two-cylinder deactivation mode considerably improves the fuel consumption at low engine load. Meanwhile the one-cylinder deactivation is an optimal fuel economy mode at medium engine load.

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Biography

Ly Vinh Dat (1979, Viet Nam). PhD of Mechanical and Electrical Engineering (2013), National Taipei University of Technology, Taipei, Taiwan. Research interests: Efficiency improvement in SI and CI engines, Intake and exhaust systems, Electro-magnetic valve train, Improving of efficiency, fuel consumption and emission in internal combustion engines, etc. Work experiences: Head of Engine Department, Faculty of Vehicle and Energy Engineering, University of Technology and Education Ho Chi Minh City, Vietnam, since 2013.

Le Nam Anh (1983, Viet Nam), Engineer of Automotive Engineering (2011), University of Technology and Education Ho Chi Minh City. He is Master student of Engineering (2012) - University of Technology and Education Ho Chi Minh City. Research interest: Improving of fuel consumption and emission in SI, CI engines.

Tran Anh Tuan (1986, Viet Nam), Master of Engineering (2014 -University of Technology and Education Ho Chi Minh City). Research interests: Vehicle Engineering, Automotive engine, Improving of efficiency, fuel consumption and emission in internal combustion engines, etc. Work experiences: lecturer in the Engine Department, Faculty of Automotive, Tran Dai Nghia University, Vietnam.