Chapter 19
Experimental and Simulated Study on the Cylinder Deactivation of Vehicle Gasoline Engine

Shuhai Yu, Xingxing Ma, Zhigang Ma, Rui Liu and Dongxian Song

Abstract Cylinder deactivation performance in vehicle gasoline engine is investigated by experimental and simulated methods, this technology is implemented by adjusting the valve system, and furthermore, a simulated model is built in GT-power. The results show that, in cylinder deactivation mode, the overlap degree of naturally aspirated and effective region is highly, it can be considered that the cylinder deactivation engine just operates in naturally aspirated state. At 2 bar@2000 rpm, BSFC of cylinder deactivation is 312.7 g/kW h, the fuel efficiency is improved 12.6% than normal state. With the reduced engine speed, fuel efficiency becomes better, however, with the increment speed, engine NVH characteristic has been deteriorated.

Keywords Cylinder deactivation · Gasoline engine · Fuel efficiency · Torsional fluctuation · Simulated study

19.1 Introduction

In recent decades, the technology of high efficiency vehicle gasoline engine had been greatly developed, such as cylinder deactivation (CDA), this technology is achieved by closing some cylinders during low load operation, and to insure the entire power output remain unchanged, the active cylinders run in higher fuel efficiency mode [1–3]. Consequently, this technology increases fuel efficiency and decreases emissions from deactivated cylinders. In most instances, the technology of cylinder deactivation is applied to relatively large displacement engines that are particularly inefficient at low load.

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First vehicle engine with cylinder deactivation system was designed in 1981 on Cadillac's 6.0L V8-engine. After that, Honda, Nissan, Volkswagen, Chrysler et al. had been performed related research about this technology to improve fuel efficiency.

In this study, the cylinder deactivation mode has been achieved by adjusting the valve system in a six-cylinder gasoline engine, the operating range and fuel efficiency between cylinder deactivation mode and normal engine mode (full-cylinder state) are compared, furthermore, 1-D engine performance simulation software GT-power has been used to investigate the cylinder deactivation engine in depth.

19.2 Experimental Setup

The test engine is designed for a 3.0L six-cylinder gasoline direct injection engine with dual-turbochargers. The implementation of cylinder deactivation is cut off fuel and air simultaneously in the deactivated cylinder. To the fuel-way, the fuel injectors of deactivated cylinders should be stopped. To the air-way, the rocker arms in the deactivated cylinder are removed thus the valve systems of corresponding cylinders become invalid. For the various engine operating conditions, oil pressure range in oil pipe is about 0.8–5 bar, thus after the remove of rocker arms, the corresponding hydraulic tappets should be fixed to avoid oil push out them.

Figure 19.1 shows the schematic of the adjusted valve system in cylinder deactivation engine, the metal clip in Fig. 19.1a provides a fixation of tappet after rocker arm removed, Fig. 19.1b is the cylinder head after adjustion, the deactivated cylinders are 1st, 2nd and 3th cylinder (three cylinders on the left side in this figure), in these three cylinders, the six valves on the intake and exhaust side are stopped; the active cylinders are 4th, 5th and 6th cylinder (three cylinders on the right side), the valve systems of these cylinders remain unchanged. The firing order is 1-5-3-6-2-4, thus all the firing interval angles are maintained 240°CA in cylinder deactivation mode, the identical angle is beneficial for the torque output evenly.

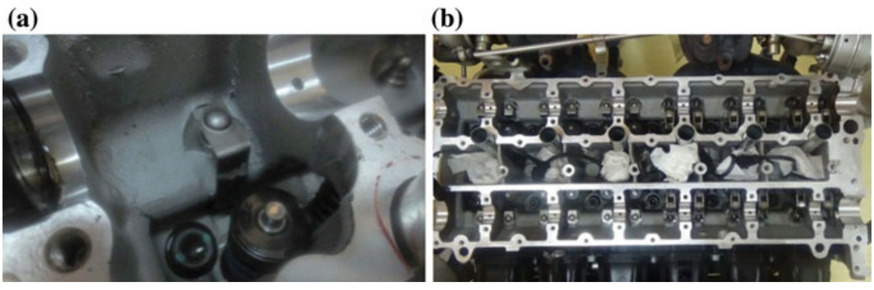

Fig. 19.1 Schematic of valve system in CDA engine. **a** Metal clip; **b** cylinder head after adjustion

Figure 19.2 shows the comparison of brake specific fuel consumption (BSFC) between cylinder deactivation mode (the left figure) and normal mode (the right figure), in the low load region (smaller than 100 Nm), fuel efficiency is improved obviously by cylinder deactivation, in the middle load region (100–120 Nm), fuel consumption is equal to normal engine, in the high load region (larger than 120 Nm), due to the decreased air-fuel ratio, fuel consumption is increased slightly. Therefore, how to determine an appropriate operating region for cylinder deactivation mode is a significant issue of the technology development.

Figure 19.3 shows the comparison of load characteristics between cylinder deactivation and normal mode, three conditions are considered such as the cylinder deactivation mode under naturally aspirated state, cylinder deactivation mode with turbocharger and normal engine mode. It can be seen that, with regard to the cylinder deactivation mode, the operating region can be divided into effective region and invalid region, in the effective region, the fuel consumption is less than normal engine, in the invalid region, the fuel consumption is greater than normal engine. According to the turbocharged state, the operating region can be divided into naturally aspirated region and turbocharged region, in the naturally aspirated region, engine operates without turbocharger and the opening angle of throttle valve increases gradually from minimum. As shown in Fig. 19.3, the overlap degree of naturally aspirated and effective region is high, it can be considered that cylinder deactivation mode just operates in naturally aspirated state, if the power output is insufficiently, the engine should switch into normal mode directly. The more accurate calibration experiment is necessary to find the precise boundary of the effective/invalid region and make this technology more effective. Additional, other load characteristics under various speed are experimented as well, such as 1500, 2000, 2400, 3200, 4000, 4500 rpm, these trends are similar as the 1000 rpm condition and not explained here. At the frequently-used operating point

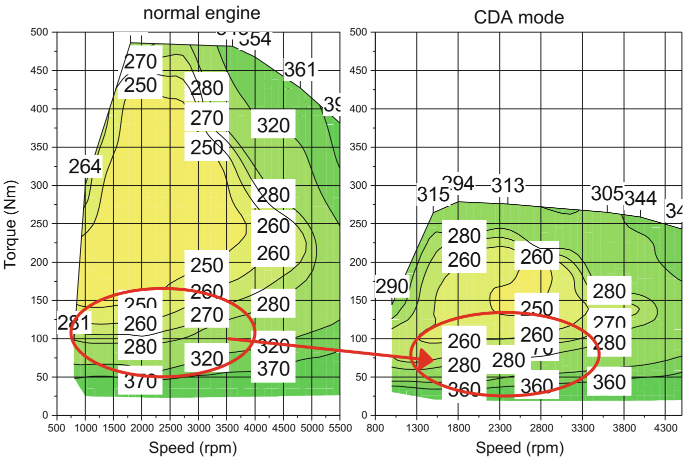

Fig. 19.2 The comparison of BSFC between CDA and normal mode

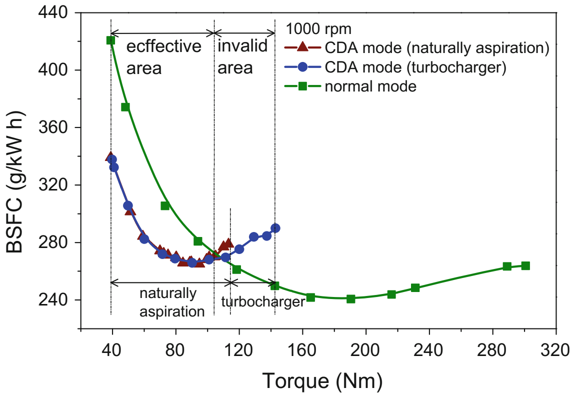

Fig. 19.3 The load characteristics comparison of CDA and original mode

2 bar@2000 rpm, which equals to 48.3 Nm@2000 rpm, BSFC of cylinder deactivation is 312.7 g/kW h, and the fuel efficiency is improved 12.6% than normal state.

19.3 Simulated Model

The GT-power software is used to simulate the engine performance. In this study, first of all, the basal normal engine model has been built and be carefully calibrated by the experimental data in full load region, Fig. 19.4 shows the comparison of experimental and simulated results, a good agreement between these two curves were obtained, especially in low-middle speed region. The CDA model is adjusted into the basal model, these adjustions include: (1) fuel injectors of deactivated cylinders are removed thus their fuel injection is stopped; (2) intake and exhaust valve lifts are defined into zero thus the motion of intake and exhaust valves are stopped; (3) ignition and combustion of deactivated cylinders model are stopped.

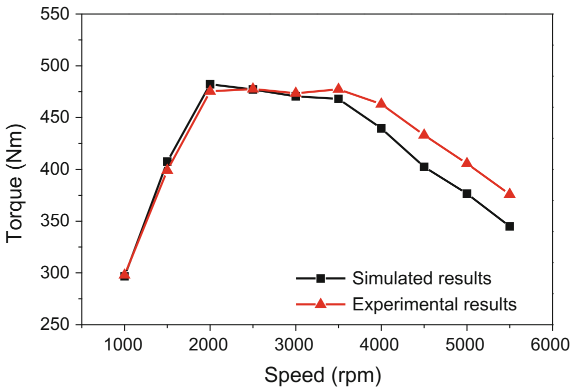

Fig. 19.4 Comparison of experimental and simulated results

19.4 Simulated Results

Based on the 1-D model as mentioned above, the simulated results are distributed into two aspects, which are (1) the comparison of various cylinder deactivation mode; (2) the comparison of various cylinder deactivation operating conditions in same mode.

19.4.1 Effect of Cylinder Deactivation Mode

The specific cylinder deactivation mode is determined by the number of deactivated cylinders. Figure 19.5 shows the comparison of maximum pressure under various cylinder deactivation mode, the engine speeds are maintained at 3000 rpm, these modes include stop 1 cylinder, stop 2 cylinders, stop 3 cylinders and stop 4 cylinders, and the difference are analyzed among them. It can be noticed that, the operating range is reduced with the increasing deactivated cylinders; furthermore, the cylinder pressure has a linear relation with engine load under all the CDA modes.

One other thing to note is the region above dotted line, namely the nearly full load region, cylinder pressure of cylinder deactivation mode is higher than normal engine (the rightmost curve), and this phenomenon lead to a risk of knock and pre-ignition which should be avoided in practical. Maximum cylinder combustion temperature is increased with the increasing pressure as well and this phenomenon deteriorated NO_x emission and thermal stress of the engine.

Figure 19.6 shows the reduction of fuel consumption under various mode, it can be seen that, fuel efficiency become better with the increasing deactivated cylinders, the reason is that to maintain power output, opening angle of throttle valve should be increased which lead to a less pump loss and a higher gas-filled efficiency; otherwise, the operating range becomes narrow and the maximum power output

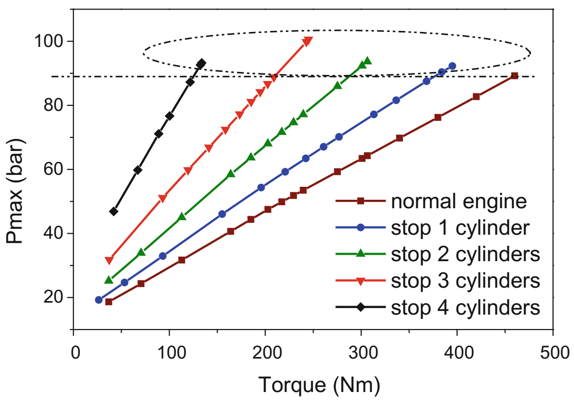

Fig. 19.5 Comparison of maximum pressure under various CDA mode

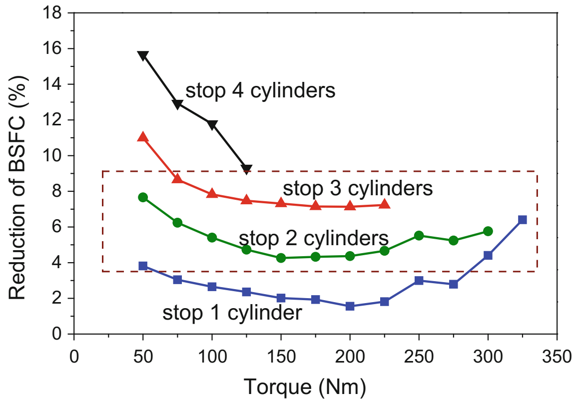

Fig. 19.6 The reduction of fuel consumption under various CDA mode

become lower with the increasing deactivated cylinders. Generally speaking, with regard to a six-cylinder engine, stop 2 cylinders or 3 cylinders is an appropriate choice to consider performance and operating range of cylinder deactivation comprehensively. To stop 2 cylinders condition, the maximum power output is 300 Nm approximately and the reduction of fuel consumption is 4–8%; to stop 3 cylinders condition, the maximum power output is 230 Nm approximately and the reduction of fuel consumption is 7–11%.

Torsional vibration characteristic of crankshaft system is an important research field in engine dynamic analysis which has a great significance on the improvement of vehicle reliability and NVH characteristics [4, 5]. Figure 19.7 shows the torsional vibration for various cylinder deactivation mode at 100 Nm@3000 rpm, the

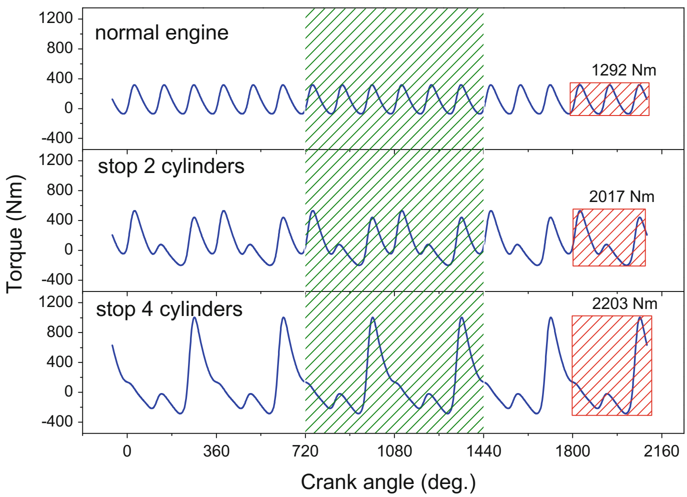

Fig. 19.7 Torque variation under various CDA mode

upper, middle and lower sub-figure represent normal mode, stop 2 cylinders and stop 4 cylinders modes, respectively. In this figure, the torsional vibration of three continuous working cycles are represented, in cylinder deactivation mode, the fire interval angles increase and vibration frequencies decrease compare with normal mode, the low vibration frequency is close to the intrinsic frequency of engine body, this phenomenon lead to a increasing vibration amplitude. When some cylinders are deactivated, the positive peak value of torque in one operating cycle will be equal to the number of active cylinders, the active cylinder load will be increased to insure the entire power output remain unchanged, thus the positive peak value of torque in cylinder deactivation mode is greater than normal engine. The vibration amplitude is 2017 Nm in normal engine operating condition, and these values are 2017 and 2203 Nm in stop 2 cylinders and stop 4 cylinders modes, respectively. Therefore, from Fig. 19.7, with the increasing deactivated cylinder, torsional vibration amplitude increases and the frequency decreases.

19.4.2 *Effect of Cylinder Deactivation Operating Condition*

With regard to the effect of cylinder deactivation operating conditions on the engine performance, take the good effective stop 2 cylinders mode (the 2nd and 5th cylinders are deactivated) as example, the load characteristics are compared under 1500, 3000 and 4000 rpm, these speeds are represented low, middle and high speed conditions, respectively.

Figure 19.8 shows fuel consumption reduction under various engine speed, to the full load condition at 1500 rpm, the fuel reduction reaches upwards of 6–9% approximately, to the full load conditions at 3000 and 4500 rpm, these reductions are 5–8% and 1–7%, respectively. It can be found that, with the decreased engine speed, the effect of cylinder deactivation is improved, in the high speed/load region, the performance is reduced.

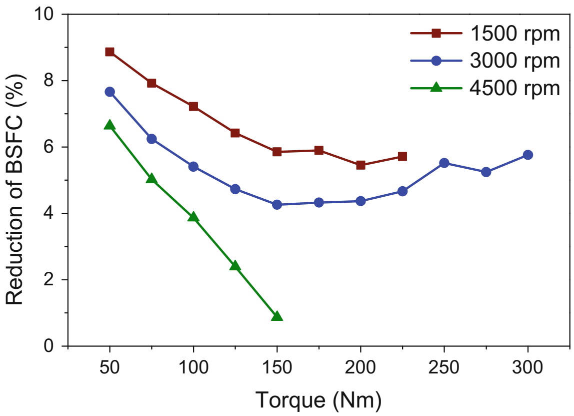

Fig. 19.8 Reduction of fuel consumption under various engine speed

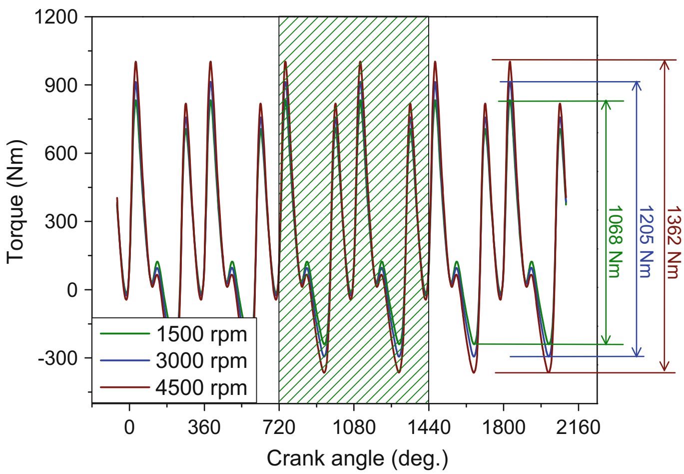

Fig. 19.9 Torque variation under various engine speed

Figure 19.9 shows the torsional variation under various engine speed, the variation amplitude under 1500 rpm is 1068 Nm, and these amplitudes are 1205 and 1362 Nm under 3000 and 4500 rpm conditions. It can be found that, with the increasing speed, variation frequency remains unchanged and negative peak value increases obviously, this phenomenon leads to the increment of variation amplitude, and affects the engine NVH characteristic adversely.

19.5 Conclusion

In this study, the cylinder deactivation performance in vehicle gasoline engine is investigated by experiment and simulation, the following are some findings from this work,

1. In cylinder deactivation mode, the overlap degree of naturally aspirated and effective region is highly, it can be considered that cylinder deactivation engine just operates in naturally aspirated state, if the power output is insufficiently, the engine should switch into full-cylinder mode directly.
2. At the frequently-used operating point 2 bar@2000 rpm, BSFC of cylinder deactivation is 312.7 g/kW h, the fuel efficiency is improved 12.6% than normal state.
3. To consider the performance and operating range comprehensively, stop 2 cylinders or 3 cylinders is an appropriate choice for 6-cylinder engine. With the reduced engine speed, fuel efficiency becomes better, however, with the increment speed, negative peak value of torque increases obviously, this phenomenon leads to the increment of variation amplitude, and affects engine NVH characteristic adversely.

References

1. Zhang D, Yuan Y, Cui Y (2007) Technology of cylinder deactivation of automotive gasoline engine. Small Intern Combust Engine Motorcycle 36(6):89–93
2. Paimon A, Jazair W, Rajoo S (2013) Parametric study of cylinder deactivation and valve deactivation for unthrottled operation. Adv Mater Res 614:525–528
3. Kwon M, Lee M, Kim J et al (2011) Transient air-fuel ratio control of the cylinder deactivation engine during mode transition. Trans Korean Soc Automot Eng 19(2):26–34
4. Yang S, Zhang F, Zhang C et al (2011) Study on torsional vibration characteristics of crankshaft in variable displacement diesel engine. Acta Armamentaria 32(09):1047–1052
5. Huang S, Zhang F, Huang Y (2011) Cylinder deactivation on dynamic performances of internal combustion engine motion mechanisms. Trans Chin Soc Agric Mach 42(9):8–13