STUDY ON THE POTENTIALS OF UNTHROTTLE AND CVVL ON IDLE AND NEDC

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ABSTRACT: In gasoline engines, partial-load operation can be controlled by varying the intake valve lift instead of throttle. In the following, FAW presents the results of study on the optimisation of intake valve lift which resolves the conflict of objectives between charge exchange and high-pressure combustion processes on idle. Furthermore, this paper also shows the potential of 10% BSFC reduced by unthrottle and CVVL with the addition of high CR and CDA(3cly to 2cly) on NEDC.

1 INTRODUCTION

The reduction of fuel consumption and thus of CO2 emission is in the key of ongoing research and developing activities. In view of different fuel qualities, two concepts found their way into modern vehicles for worldwide application. On the one hand this is the concept of downsizing, where high specific power is reached by turbocharging. To reach a good response behavior, these engines are more and more equipped with direct fuel injection and homogeneous mixture distribution [1, 2]. On the other hand high efficiency is reached by reducing friction and pumping losses. An effective way to reduce pumping loss is the unthrottle engine operation at part load with mechanical fully variable valve actuation. This technique was introduced by BMW in 2001 and later introduced by several other car manufacturers like Toyota, Mitsubishi, Nissan and Honda with their own valve train systems [3]. The fuel direct injection with stratified mixture distribution and turbocharging has high potential to reduce fuel consumption but high demands on mixture preparation and in- cylinder flow. This technology is in the key of research and development activities [4]. Future concepts to increase the efficiency will combine different technologies like DI, boosting and variable valve actuation. As a precursor of mechanical fully variable valvetrains, BMW already offers such engines in the market which realizes the combination of DI, turbocharging and CVVL (TVDI) [1].

2 METHODOLOGIES AND TEST ENGINE

Engine test is performed on FAW's four-valve 4-cylinder research engine with a high degree of variabilities. The engine's geometric data and other variabilities are shown in Table 1, as well as simulation on idle and part Load (NEDC points) conditions by GT-Power is shown in Fig. 1.

Table 1 Engine configuration

Engine configuration	Unit	Value
Bore	[mm]	72
Stroke	[mm]	73.6
Valve	[-]	4
Compression ratio	[-]	12
Maximum valve lift intake / exhaust	[mm]	8/8
Cam phasing intake / exhaust	[℃A]	60/50

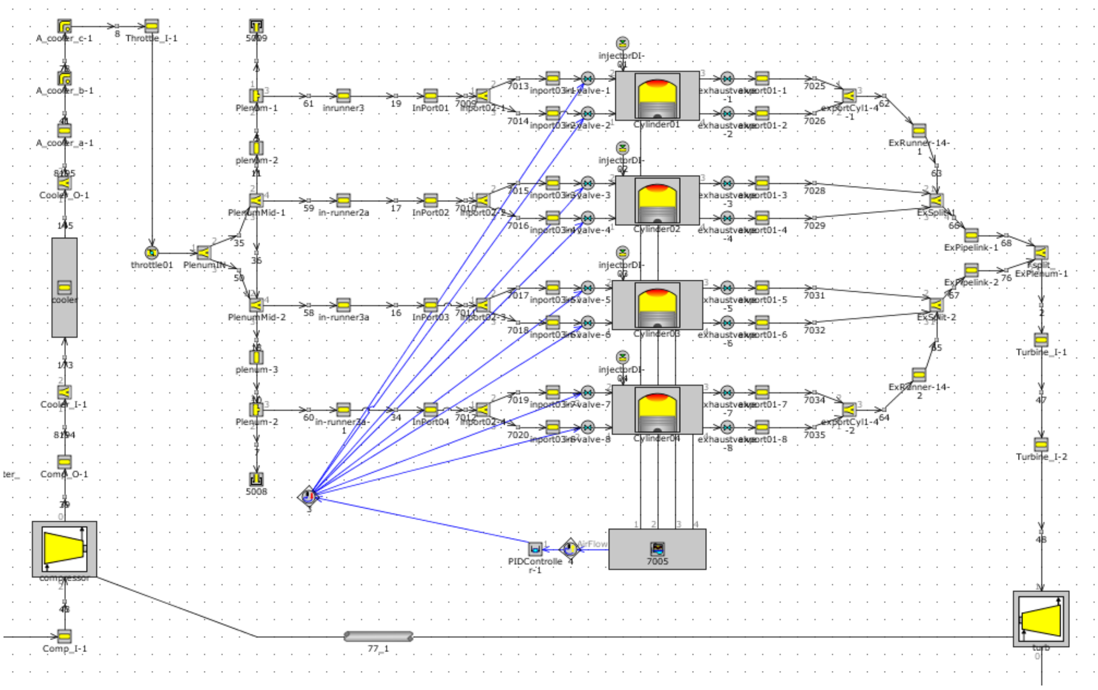

Fig. 1 Simulation by GT-Power

The fuel consumption at part load with throttle-free load control can be either reduced through a decrease of the pumping mean effective pressure PMEP (charge cycle work) and an increase of the amount of residual gas or a reduction of friction. The pumping mean effective pressure at throttle-free load control can be, for example, influenced by the valve lift duration and the spread of the in- and outlet side.

3 IDLE UNTHROTTLED ON PMEP

The simulation is performed on the condition of 750rpm idle speed, 0 bar BMEP and 7.1kg/h airflow rate, which are the same with dyno data. Six lifts from 0.3mm to 1mm is given for the simulation and the relation between lift and duration is not considered in this paper. Every lift can meet target airflow, but they are respectively corresponded to different duration. The details are shown in Fig. 2.

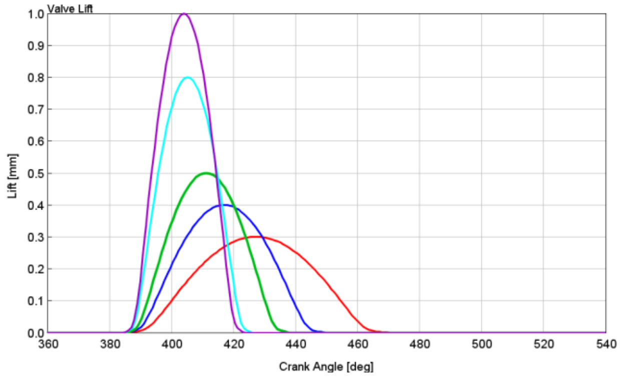

Fig. 2 Six lifts from 0.3mm to 1mm

Fig. 3 shows the influence of the intake valve lifts on the PMEP for throttled as well as throttle free modes with GDI and 6 different lifts for an engine operating point of idle. In the tests, the amount of PMEP is approximately decreases by 28 % at 1mm.

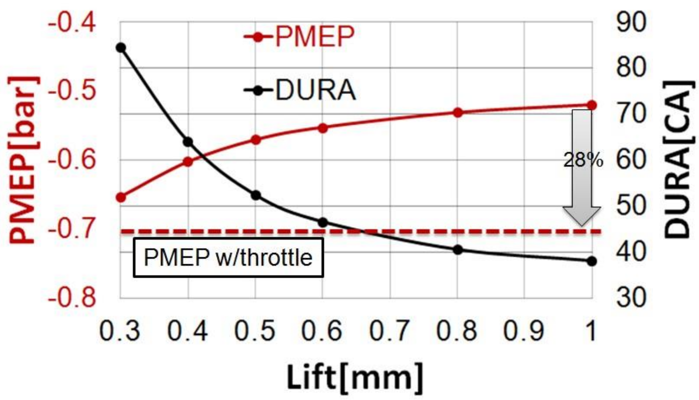

Fig. 3 Influence of PMEP & duration over lift (IVO = 385)

Fig. 4 shows LP P-V diagram between throttled and throttle free modes. The results explain why PMEP decreases. If IVO (385) is too late, the result can still be optimized by suitable IVO, so that PMEP can be drastically reduced with Miller timing, especially in comparison with early IVC. For example, 1 mm lift with small duration can make IVC earlier, so PMEP is smaller.

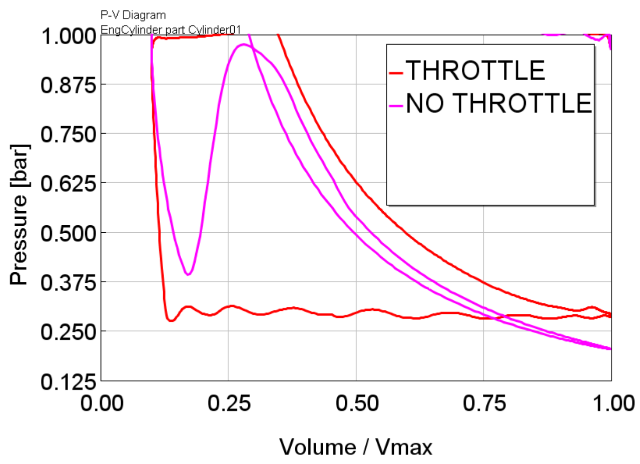

Fig. 4 P-V diagram between throttled and throttle free modes (the lift is 1.0 mm)

Fig. 5 shows the influence of the inlet lift on the PMEP for throttled as well as throttle free modes with GDI and three different IVO for an engine operating point of idle. The results show that, the best IVO for PMEP is around 360 (TDC), which decreases about 17% PMEP with 0.3mm inlet lift compare to IVO = 385. For IVO = 360, PMEP decreases approximately 33 % with 1mm inlet lift compared with throttled. At best IVO, the influence of inlet lift on the PMEP becomes smaller and smaller, while tumble ratio, turbulent kinetic energy and combustion become more important.

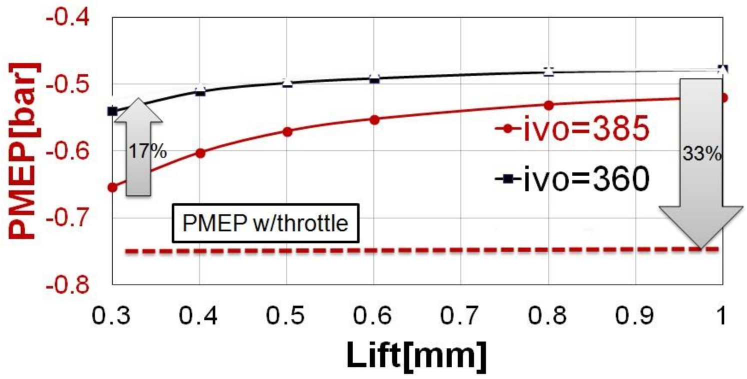

Fig. 5 PMEP over lift at different IVO

Fig. 6 shows LP P-V diagram between throttled and throttle free modes. Apparently, the best IVO (360) has lower pumping losses than IVO = 385.

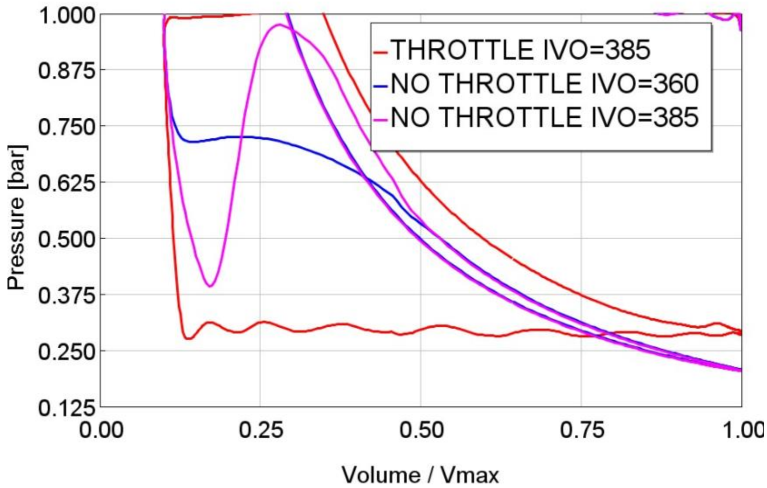

Fig. 6 P-V diagram between throttled and throttle free modes (different IVO, the lift is 1.0 mm)

4 IN-CYLINDER FLOW AND COMBUSTION OF IDLE UNTHROTTLED

Fig. 7 shows the effect of idle unthrottled on in-cylinder flow. Because of the small lift in the early intake valve closing, the value of tumble ratio and turbulent kinetic energy has a big drop which causes the worst flow performance.

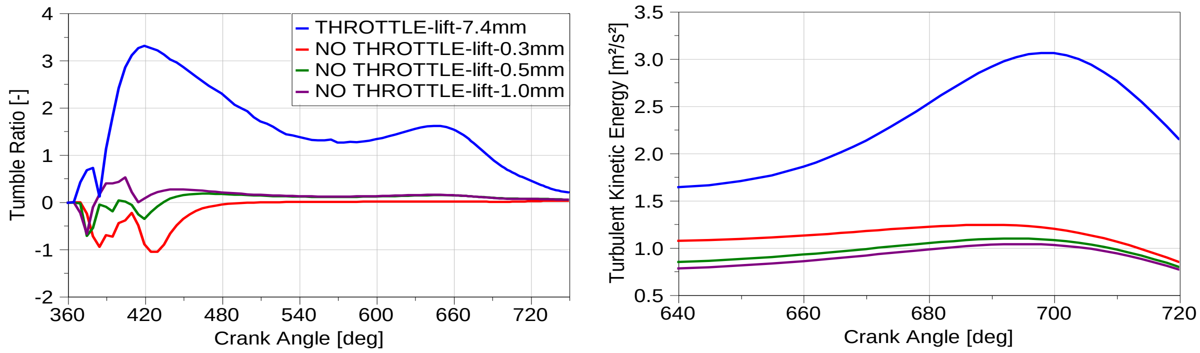

Fig. 7 Effect of idle unthrottled on in-cylinder flow

Fig. 8 shows the comparison of four different lifts in flow field. The three small lifts cause most of the fresh air into the combustion chamber through the bottom of the intake port and lead to a reverse tumble. After the intake valve closes, the reverse tumble decreases quickly. As a result, the turbulent kinetic energy is at a low level compared with throttle.

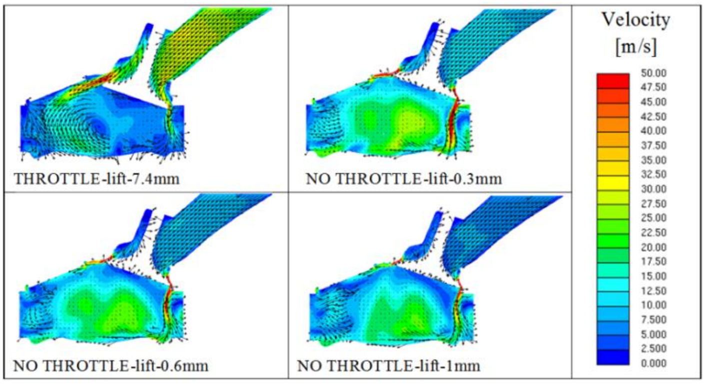

Fig. 8 Comparison of flow field

In the gasoline engines, it is well known that turbulence intensity plays an important role to enhance combustion and Damköler's argument has been had a strong influence on combustion research since 1940[5]. Fig. 9 shows that, due to the low level of turbulent kinetic energy for no throttle, the combustion duration increase approximately 3 CA °compared with throttle, while the three small lifts for no throttle are at the same level.

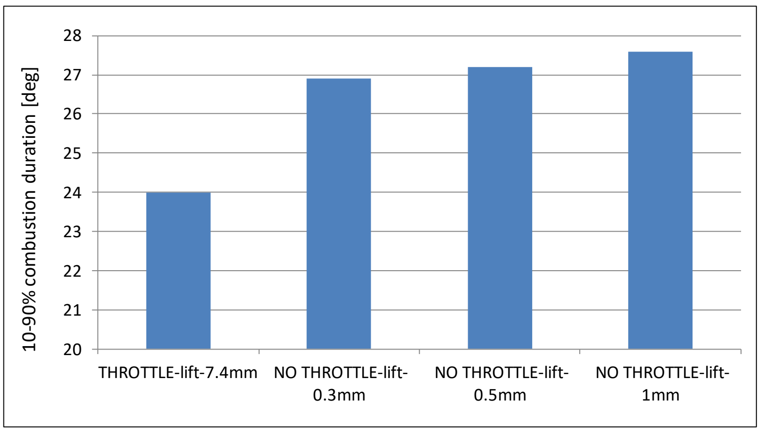

Fig. 9 Combustion comparison

5 ATTEMP TO INCREASE THE turbulent kinetic energy FOR IDLE UNTHROTTLED

In order to increase the turbulent kinetic energy for idle unthrottled, it need to enhance in-cylinder tumble flow and thus two methods are implemented which are shown in Fig. 10. The one is tumble flap, the other one is optimized intake port with higher tumble ratio.

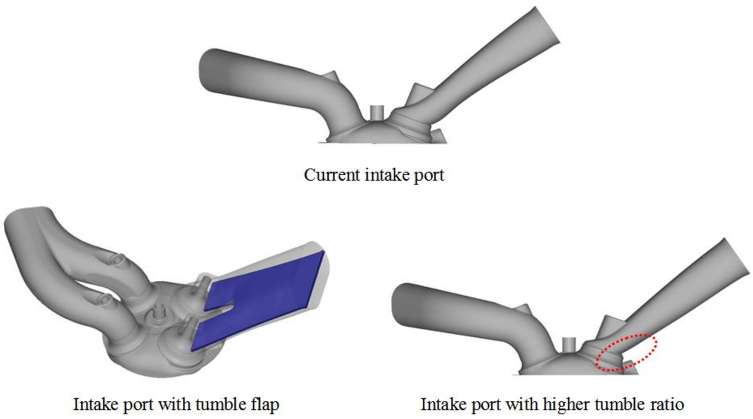

Fig. 10 methods to enhance in-cylinder tumble flow

Fig. 11 shows the comparison of in-cylinder flow. The results show that, the two methods have no effect on increasing the tumble ratio and turbulent kinetic energy. Fig. 12 shows the comparison of flow field. The results show that, because of the small intake valve lift, the tumble flap in the intake port or increasing the tumble ratio of the intake port couldn’t prevent most of the fresh air flowing into the combustion chamber through the bottom of the intake port. Therefore, the reverse tumble still exits.

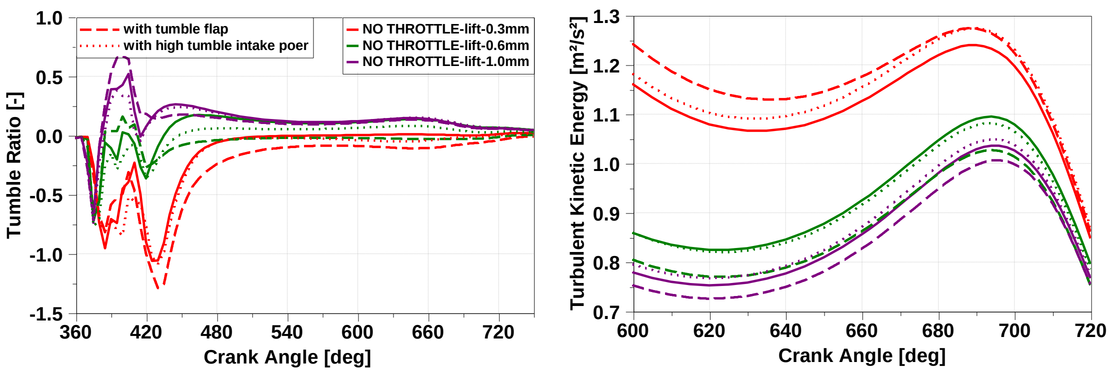

Fig. 11 Comparison of in-cylinder flow

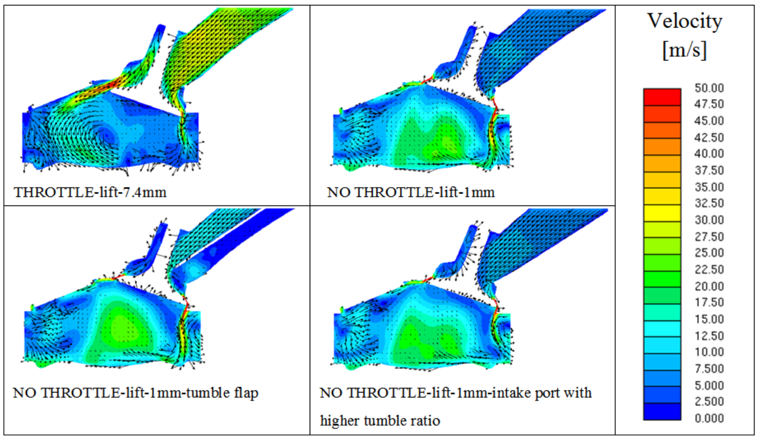

Fig. 12 Comparison of flow field

6 FC OF UNTHROTTLED ON NEDC

Fuel consumption of NEDC is simplified as nine engine operation points which have their own weight in this paper. This is a simply way to calculate fuel consumption of NEDC and can give a quantitative comparison of technical measures, as shown in Table 2 and Fig. 13. The technical measures are: high CR(12), unthrottle by CVVL and CDA (3cly to 2cly).

Table 2 Nine operation points

point number	Speed r/min	Torque Nm	BSFC g/kWh	Weight %
1	2503	121	g1	12.3%
2	2513	81	g2	13.8%
3	1801	64	g3	11.8%
4	2125	63	g4	12.9%
5	2385	59	g5	12.8%
6	1193	39	g6	6.6%
7	1837	36	g7	17.9%
8	1625	15	g8	6.1%
9	2378	8	g9	6.0%

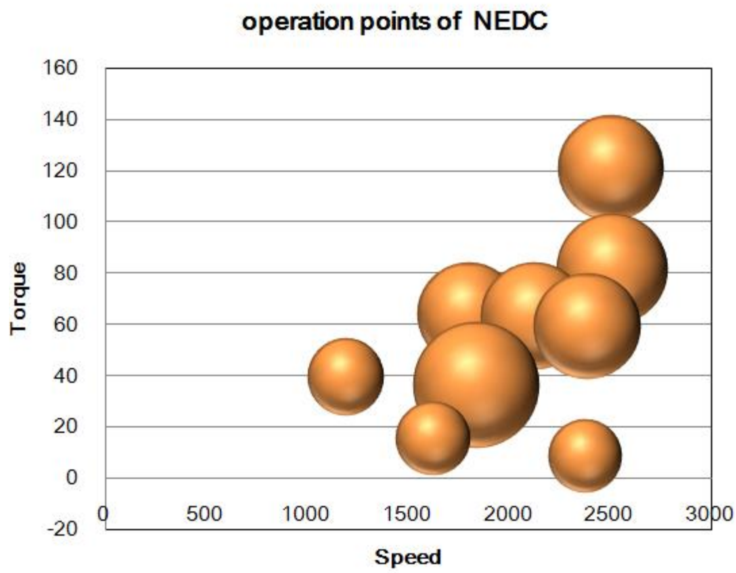

Fig. 13 Nine operation points

Simulation is performed on GT-Power using FAW's four-valve 3-cylinder research engine with a high degree of variabilities. The engine's geometric data and other variabilities are shown in Table 3.

Table 3 Engine configuration

Parameter	Unit	Value
Bore	[mm]	72
Stroke	[mm]	81.8
Valve	[-]	4
Compression ratio	[-]	10
Maximum valve lift intake / exhaust	[mm]	8/8
Cam phasing intake / exhaust	[℃A]	60/50

It can be seen in Fig. 14 that, PMEP has a sharp decrease on all points, especially for point 2, 3 and 5, which is more than 0.3bar improvement (Fig. 14(c)). For low loads like points 8 and 9, a fuel consumption and associated CO_2 benefit can be observed by more than 10% (Fig. 14(d)).

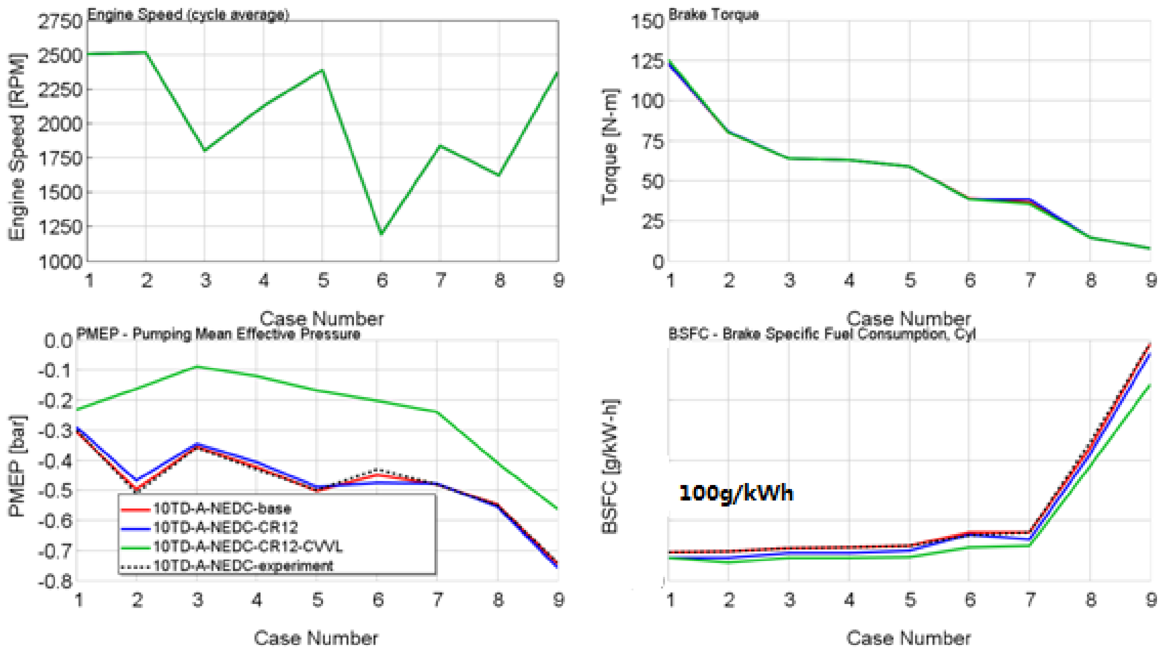

Fig. 14 PMEP and BSFC of different technical

It can be seen in Fig. 15 that, IVO can be set the same valve of 360; IVC become earlier as load is lower (EVO and EVC can also keep fix if use unthrottle). The burned mass percent at combustion start (EGR + Resid) is smaller.

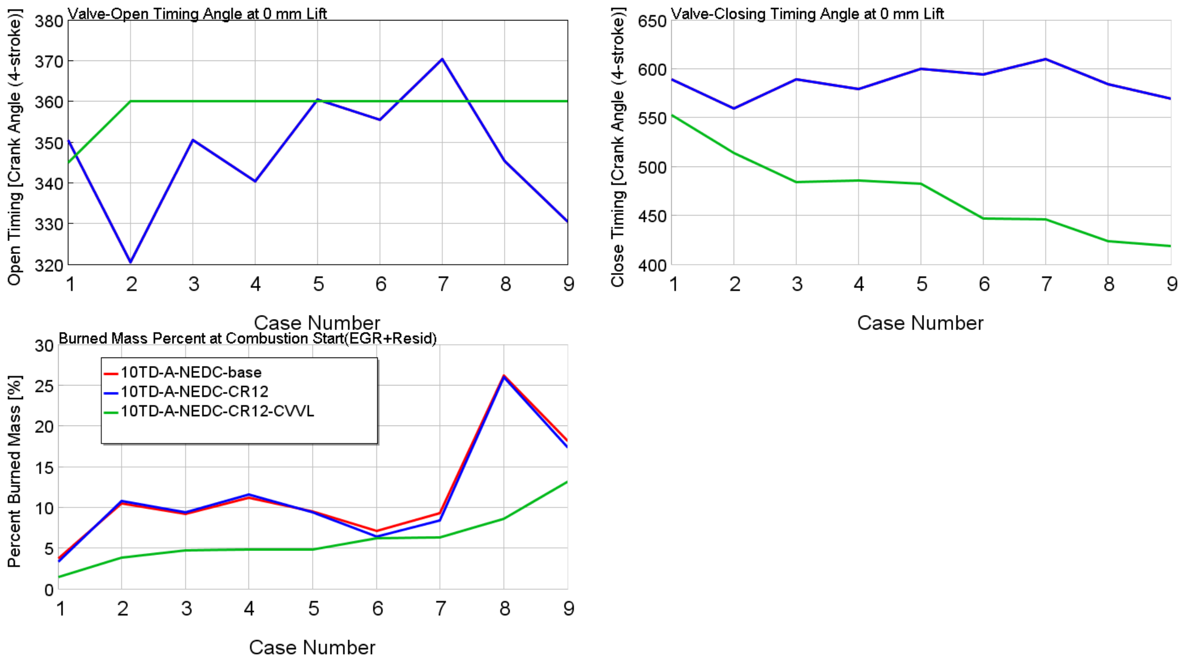

Fig. 15 IVO, IVC and PBM of different technical

It can be seen in Fig. 16 that, increasing CR can improve FC of NEDC by 3.4% while CVVL can improve FC of NEDC by another 4.3% only on PMEP. After adding CDA (3cly to 2cly), there are nearly 10% can be observed in total.

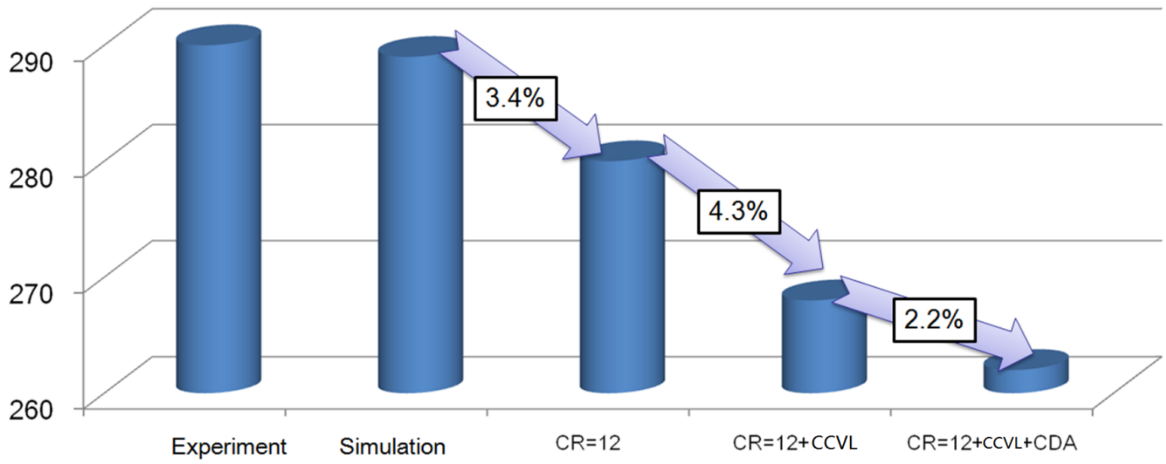

Fig. 16 NEDC cycle FC of different technical

7 SUMMARY AND CONCLUSIONS

A simulation study has been conducted to investigate the benefits of unthrottle on spark-ignited engines. By combining these strategies with cam phasing, significantly improved fuel economy on idle and NEDC has been demonstrated. These strategies reduce pumping losses for improved indicated thermal efficiency. While results are expected to be application dependent, the following conclusions may be made:

• Best IVO is 360 CA °ATDC, higher lift with small duration is better for reducing pumping losses at idle.

• Unthrottle with high CR improves fuel economy by about 10% compared with a DVVT baseline without EGR, or about 8% compared with the same engine without CDA (3cly to 2cly)

• For unthrottle, the tumble ratio and turbulent kinetic energy have a big drop compared with throttle, and the three small lifts from 0.3mm to 1mm are at the same level. The combustion duration of unthrottle increase approximately 3 CA °compared with throttle.

•Application of tumble flap in the intake port or increasing the tumble ratio of the intake port have no effect on increasing the tumble ratio and turbulent kinetic energy.

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