Study on the influence of masking on the high tumble intake ports of GDI engine by three-dimensional simulation

Lu Xu 1, Peng Hu 2 and Fuqiang Luo 1, *

1School of Automotive and Traffic Engineering, Jiangsu University, Zhenjiang, China
2Chery Automotive Co., Ltd., Wuhu, China

*Corresponding author e-mail: luofq@ujs.edu.cn

Abstract: The high intensity tumble motion has a significant effect on the combustion system and the thermal efficiency of gasoline engine. The tumble ratio and discharge coefficient of high tumble ratio intake ports with masking were simulated by CFD three-dimensional simulation. The influence of masking on the intake process was emphatically discussed. The width, height, radius fillet and circumferential range of masking were changed and then simulated. The results shown that, the tumble intensity at the low valve lift was greatly affected by the masking. The smaller width, higher height, smaller radius fillet and larger circumferential range are favorable for the higher tumble intensity in low valve lift and also higher in average tumble ratio. Among these parameters, masking height has much more effect on mean tumble ratio and mean discharge coefficient. When the valve lift exceed masking height, the difference of tumble ratio and discharge coefficient between intake ports decreased.

1. Introduction

The demand for energy conservation in various industries is raising higher and higher with the increasing energy consumption. Fuel economy regulations from different countries are more and more stringent for internal combustion engine, promoting its development of high efficiency and energy saving. One of the most effective measures to reduce fuel consumption is to improve the thermal efficiency of the internal combustion engine [1]. For GDI (Gasoline Direct Injection) engines, it can enhance fuel economy by optimizing combustion process and combining with other technical strategies like turbocharging technology, exhaust gas recirculation, high tumble ratio intake system and Miller Cycle technology [2].

Tumble motion is a kind of large scale flow motion in the cylinder whose axis is perpendicular to the axis of the cylinder. It forms during the intake process and breaks up into turbulence with the piston going up in the end of compression stroke. High tumble motion intake system for GDI engines is conducive to well-organized fuel-air mixing and plays an important role in accelerating flame propagation rate, reducing combustion cycle fluctuation and promoting high efficiency combustion [3-5]. Previous researches have been investigated the design and development of intake ports by CFD numerical simulation. However, most of the existing studies focused on the analysis and improvement of PFI (Port Fuel Injection) gasoline engines, little research has been done on the high tumble ratio intake ports of high efficiency turbocharged GDI engines [6].
Steady-state and transient intake port simulation combined with intake port steady-flow experiment and various micro-measurement techniques have been done by different scholars and experts, which displayed the air flow condition in cylinder and indicated that the structure of the intake port was the main factor of affecting the tumble ratio[7]. In this paper, the discharge coefficient and tumble ratio of masking intake ports[8] are simulated by steady-state simulation and the influence of masking structure parameters on intake parameters is discussed emphatically.

2. Structure of high tumble ratio intake ports with masking

The investigation is carried out on a Chery 1.6 TGDI hybrid vehicle with four valves, which aimed at high thermal efficiency. The engine parameters is shown in Table 1.

| Items                     | Parameters |
|---------------------------|------------|
| Engine type               | Straight four engines |
| Diameter/mm×Stroke/mm     | 77×85.8 |
| Total displacement /L     | 1.598 |
| Maximum valve lift /mm    | 8         |

The tumble motion in the cylinder majorly depends on the structure of the intake port. The prototype is a high tumble ratio intake port. The air flow distribution in the upper part of the throat section in the intake port has a great influence on the tumble motion. The lower part of the intake port is designed as a fish-belly structure to guide air flow more into cylinder through the upper space. The upper wall of the intake port is straight and tangent, reducing the vertical height of the throat section, as shown in fig.1 (a). Masking structure was established at the lower side of the intake port outlet near the cylinder wall to prevent the air flow from going into cylinder, which is beneficial to improving the tumble intensity, as fig.1 (b) shows.

![Fig. 1](a) High tumble ratio intake ports without masking, masking(blue shadow)

![Fig. 2](a) Width and height of masking, (b) 90° circumferential range, (c) 1mm fillet radius

The effect of masking on the intake parameters, especially the tumble ratio, is mainly discussed in the flowing part. Fig. 2 shows the masking structure parameters.
3. Simulation model and validation
AVL-FIRE software was adapted to simulate steady-state intake flow of high tumble intake port model. The surface mesh and volume mesh are done by Hypermesh and AVL-FIRE FAH strategy, respectively. The valve lift starts at 1mm and grows gradually to 8mm by range of 1mm, so each intake port has 8 models. The maximum, the minimum and the refinement area size is 2 mm, 0.5 mm and 0.25 mm respectively. The total mesh number is about 800 thousands. In the simulation, the boundary conditions of pressure difference between inlet and outlet are constant 2.5 kPa at atmospheric pressure, which is consistent with the experiment condition. K-zeta-f turbulence model and Hybrid Wall Treatment wall function are selected. The simulation surface is the cross section which is 0.5D from the top dead center (D is cylinder diameter).

In order to verify the correctness of model, the discharge coefficient and tumble ratio obtained from the steady-state simulation are compared with the value measured by the steady flow test bench. The results are shown in Fig. 3. The largest error between the two curves is within 7%, indicating that the model and simulation methods are reasonable.

![Comparison of experiment and simulation results](image)

4. Results and discussion

4.1. Effect of different masking width on intake process
Fig. 4 shows the simulation results of intake ports without masking and different masking width. Intake ports with masking has high tumble intensity at low valve lift. The cause is that blocking effect of masking is much better at lower valve lift. With the decrease of masking width, the throttling effect is remarkable and tumble intensity raises at the same valve lift (0.2 mm masking width is only for simulation study, and the minimum is 0.5 mm in engineering). The masking blocking effect on air flow decreases when the valve lift exceeds masking height, leading to sharp augment of the air flow area. The masking height is 2mm in the Fig.4, so the tumble strength decreases after 2mm. As the valve lift continues to upgrade, the variation of tumble ratio and discharge coefficient is no longer evident. The discharge coefficient of masking is lower at small valve lift while a little higher at large valve lift on account of the trade-off relationship.

There are different evaluation methods to calculate average tumble ratio and average discharge coefficient [9-11]. The AVL evaluation method is selected to analyze the flow performance and compared with the other two methods, Ricardo method and FEV method. It can be seen that reducing the masking width lead to a slightly improvement of AVL average tumble ratio.
4.2. Effect of different masking height on intake parameters

Changing the masking height will affect the blocking effect. Fig. 5 indicates the variation of tumble ratio and discharge coefficient when masking height is from 1 mm to 5 mm (masking width is 0.5 mm). The tumble intensity is higher when valve lift is lower than masking height but decreases to a minimum value when the valve lift grows up to more than masking height, and then raises up. At largest valve lift, the intake port with higher masking height has lower tumble intensity, because negative vortex weakens positive tumble motion.

![Fig. 5](image)

The discharge coefficient variation is more obvious in the middle and small valve lift (2 mm to 5 mm). The discharge coefficient difference become small when the valve lift is beyond 6 mm, exceeding highest masking height, since the throttling effect is not clear. When the masking height changes from 1 mm to 5 mm, the average tumble ratio of AVL increases by 4.7%.

4.3. Intake process parameters of different masking fillet radius

The fillet radius will also impact the blocking effect according to the structural characteristics of masking. The larger fillet radius lead to the smaller throttling effect. The following diagram compares the masking fillet radius of 1 mm, 2 mm and 3 mm (masking width and height are 0.5 and 3 mm, respectively). It can be seen that the tumble intensity is higher at low valve lift (1 mm to 3 mm) as 1 mm fillet radius intake port has higher intensity than 3 mm fillet radius. The tumble ratio and discharge coefficient are almost the same at middle and large valve lift. When the fillet radius of masking changes from 3 mm to 1 mm, the AVL average tumble ratio increases by 3.8%.
4.4. Effect of different masking circumferential range tumble on intake parameters

The effect of the masking circumferential range on the intake process is shown in Fig. 7. The influence of circumferential range on tumble strength and discharge coefficient is relatively small. Since the blocking effect raise up with the circumferential range increment, tumble intensity is lowest at 90° while is highest at 180° within 1-3 mm valve lift. More than 4 mm valve lift, the tumble ratio and discharge coefficient are almost the same. The AVL average tumble ratio of 180° range is 2.4% larger than 90°.

5. Conclusion

(1) The airflow obstruction structure masking has a great influence on tumble ratio and discharge coefficient at the low valve lift. Compared with intake port without masking, tumble strength of masking intake port were significantly higher at low valve lift, but slightly smaller at high valve lift. The variation trend of discharge coefficient is opposite.

(2) Masking structural parameters have vital effect on intake performance. Narrow width, small fillet radius, high height and large circumferential range are the favorable conditions to improve tumble ratio at low valve lift and average tumble ratio.

(3) AVL average tumble ratio are from 3.0 to 3.7. Masking height has the greatest influence on the average tumble ratio and discharge coefficient. The AVL average tumble ratio increases by 4.7% with the masking height from 1 mm to 5 mm. The effects of other structural parameters on the tumble ratio are between 2%-4%.
Acknowledgements
This research is purported by the key research and development plan No. 2017YFB0103402 of Chinese Science and Technology Department.

References
[1] Lee B, Oh H, Han S K, et al. Development of high efficiency gasoline engine with thermal efficiency over 42%: International Powertrains, Fuels & Lubricants Meeting, 2017[C].
[2] ZHANG Manfu, ZU Bingfeng, WANG Zhen. A study on the effect of ultrahigh tumble on the combustion system of a high thermal efficiency gasoline engine [J]. Chinese Internal Combustion Engine Engineering, 2018,39(02):29-34.
[3] Fu J, Zhu G, Zhou F, et al. Experimental investigation on the influences of exhaust gas recirculation coupling with intake tumble on gasoline engine economy and emission performance[J]. Energy Conversion & Management, 2016,127:424-436.
[4] Omura T, Nakata K, Yoshihara Y, et al. Research on the Measures for Improving Cycle-to-Cycle Variations under High Tumble Combustion: SAE 2016 World Congress and Exhibition, 2016[C].
[5] Yoshihara Y, Nakata K, Takahashi D, et al. Development of High Tumble Intake-Port for High Thermal Efficiency Engines: SAE 2016 World Congress and Exhibition, 2016[C].
[6] LI Yufeng, LIU Shuliang, SHI Xiaoxi, A study of increasing in-cylinder tumble intensity of four-valves S.I. engines [J]. Transactions of CSICE, 1999,17(03):263-266.
[7] WANG Shunchao. The research on flow field in ports and cylinder of 167FMI gasoline engine[D]. Chongqing University, 2016.
[8] Millo F, Luisi S, Borean F, et al. Numerical and experimental investigation on combustion characteristics of a spark ignition engine with an early intake valve closing load control[J]. Fuel, 2014,121(121):298-310.
[9] Liu D, Jia M, Wang T, et al. Insights into the development of the tumble motion using the direct and indirect steady-flow test methods[J]. Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering, 2014,228(13):1530-1546.
[10] XIA Xinglan, CHEN Dalu, WANG Shengli. Evaluation methods to performance of intake port internal combustion engine [J]. Modern Vehicle Power, 2007,126(2):7-12.
[11] LAN Zhibao, QIN Jihong, YANG Xiao, et al. influence of intake port on air flow characteristics and performance of turbocharged gas