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Intake Flow Interference Analysis of Combination Intake Port in Diesel Engine

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ABSTRACT

In order to analyze the intake flow characteristics of a four-valve direct injection(DI) diesel engine, the experiments and numerical simulations were conducted to investigate the flow coefficient, swirl ratio and intake flow interference of the following 4 combinations of intake ports: (1) helical (left) and tangential (right), abbreviation ; (2) tangential (left) and helical (right); (3) helical (left) and helical (right); and (4) tangential (left) and tangential (right).Results show that the relative flow coefficient and swirl ratio could be directly reflect the interference of combined intake port, and when the ratio was close to 1, which showed that intake port had less interference ;and when the ratio was close to 0, which showed that the interference was serious. The relative flow coefficient of the 4 combinations of intake ports has little difference, but the relative swirl ration had significant difference in the whole valve lift range. And there had little interference between adjacent intake ports, but the swirl was strongly formed in cylinder at the maximum valve lift.

Keywords: Four-valve; Diesel engine; Combined intake port; Intake flow interference.

NOMENCLATURE

D	cylinder diameter
SR_c	relative swirl ratio
SR_{actual}	actual swirl ratio
SR_{theo}	theoretical actual swirl ratio
h_V	valve lift
μ_c	relative flow coefficient
μ_{actual}	actual flow coefficient
μ_{theo}	theoretical flow coefficient

1. INTRODUCTION

Diesel engine combustion imposes stringent requirements on in-cylinder mixture formation and flow; good mixture can improve combustion efficiency and power, and reduce oil consumption and emissions. At present, for medium-size and small-size high-speed diesel engines, the 4-valve structure is main valve type, which is composed of two intake valves and two exhaust valves, and the combination pattern of the two intake ports and position is the design and matching key of the air intake system design, burning room and oil system to diesel engine (Yufeng *et al.*, 2001).Currently, there are mainly two types of inlet ports in diesel engine, tangential and helical. The helical port can provide the swirl of the mixture air formation, and the tangential port has little flow resistance, and the combination port of the helical and tangential ports can provide enough intake air for mixture gas formation and burning. However, when the diesel engine works, the mutual influence and interference motion of the air flow takes place at the two adjacent intake ports in the process of intaking air process, which will affect the intake air flow and swirl formation. Therefore, in order to research the mixed air flow field in cylinder and develop high-efficiency and low-emissions four-valve-head diesel engines, it is important to systematically study the interference rule of the combined intake ports (Sun *et al.*, 2007; Ziyu *et al.*, 2014).

The domestic and foreign scholars design and analysis the steady-state flow test bench of intake ports and analyze the flow characteristics of intake ports by ports experiment and simulation method (Kawaguchi *et al.*, 2009; Andreatta *et al.*, 2008; Desantes *et al.*, 2001; Deqing *et al.*, 2004; Wang Tianyou, *et al*. 2008), but it is

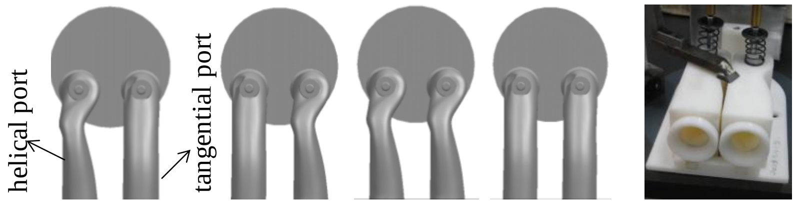
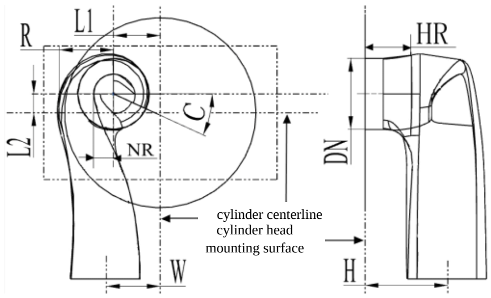


Fig. 1. Scheme of the intake port types and prototype.

Table 1 Specifications of the intake port



R	outer radius of volute	L1	lateral positioning to cylinder centerline
C	spiral termination angle	L2	longitudinal orientation to cylinder centerline
W	inlet width of intake port	NR	inner radius of volute
H	inlet height of intake port	HR	spiral chamber height
		DN	intake port throat diameter

Table 2 Basic parameters of the diesel engine

item(units)	parameters
bore×stroke/mm	80×92
maximum valve lift/mm	8
compression ratio	16.5
combustion chamber type	ω
maximum torque/N·m	125
maximum torque speed/r·min^{-1}	2200
rated power/kW	41
rated power speed/ r·min^{-1}	4000

difficult to directly study the flow interference at adjacent intake ports by experimental method. In order to resolve the previous research on the flow interference of intake ports, the flow coefficients and swirl ratios of these combinations of intake ports were measured and analyzed by test bench, and 3D models of four different combinations of intake helical port and tangential port were established by using the Unigraphics (UG) software. The CFD software "Fire" was used to simulate intake flow interference characteristics at various valve lifts.

2. Flow Analysis Model Of Combination Intake Ports

2.1 3D Model of Intake Ports

To analysis the intake air flow, the accurate combination intake ports is built, as shown in Fig.1:(1) helical (left) and tangential (right), scheme 1; (2) tangential (left) and helical (right), scheme 2; (3) helical (left) and helical (right), scheme 3; and (4) tangential (left) and tangential (right), scheme 4. The four combined intake ports have the same volume.

The intake port and diesel engine main parameters are shown Table1 and Table 2.

2.2 Simulation Model of the Combination Intake Port

（1）Building the flow simulation model

A geometry model was developed, which is consisted of a rectangular stabilizing chamber for intake air pressure, two intake ports, two intake valves, two valve seats, and a cylinder. And automatic mesh generation was conducted by using the AVL FIRE pre-treatment function module for the ports, and the mesh of the valve face and the valve seat was refined, as shown in Fig. 2.

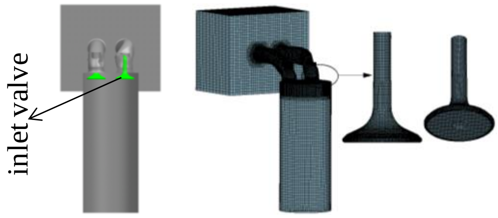


Fig. 2. Flow simulation model of the combination intake ports.

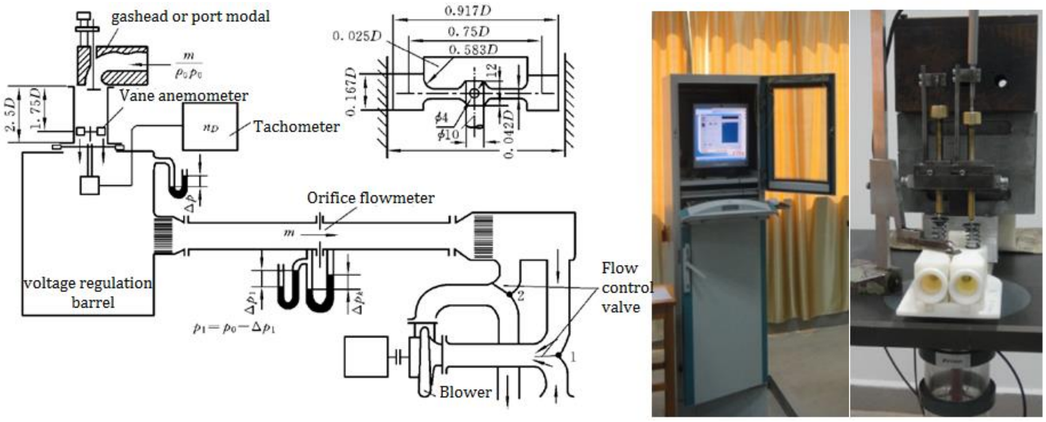


Fig. 3. Steady-state flow bench of intake port testing.

Table 3 Parameters of boundary condition

item(units)		parameters
total pressure /kPa		100
constant-pressure-differential of the inlet and outlet intake port	small valve lift	6.5k Pa
	high valve lift	2.5k Pa
intake port temperature/K		293.5
turbulent length/m		0.001
boundary turbulent kinetic energy/ m^2/s^2		1

（2）Boundary condition

Testing was conducted by using a constant-pressure-differential method, no-slip on wall surfaces, adiabatic, and fixed wall surface temperature, and the detailed parameters are shown in Tab.3

（3）Simulation method

The steady-state method was used in numerical simulations. The Minmod Relaxed Difference scheme was used to solve the momentum conservation equation. The fluid in the model was compressible gas. Standard wall functions were used for surface treatment and wall heat transfer. The k-ε double function model was used for the turbulence model. When the pressure, momentum, and turbulent kinetic energy residual reached less than 10^{-4}, the computation was considered to achieve steady convergence (Changming *et al*., 2009).

1.3 Simulation Model Validation

The flow coefficient and swirl ration was tested by AVL ports steady-state bench, which provided the basis for the interference of the air intake flow. The steady-state flow bench is shown in Fig. 3, the length of the simulated air cylinder was set as 2.5D, and vane was positioned at a distance of 1.75D away from the top of the cylinder head, where D is cylinder diameter, The AVL intake port steady flow test rig is used to measure the flow coefficient and vortex ratio, which provides the basis dates for the interference of intake flow, test rig is shown in Fig.3, and the length of the recommended value of simulated cylinder is 2.5D in the figure, blade distant from cylinder head top is1.75D.

Testing was conducted by using a constant-pressure-differential method on the test bench, and the valve lifts of the combination intake ports used in testing and numerical simulation were set at 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, and 8 mm, respectively, to investigate port flow characteristics. The flow coefficient and swirl ratio of the combined intake port were compared with the single spiral and tangential ports. Only the scheme 2 was analyzed, as showed in Fig.4 and Fig.5.

As show in Fig.4, the flow coefficient increases with the valve lift, and there is less difference when the valve lift is less than 3 mm, but the flow coefficient of the scheme2 is between the spiral and tangential ports, and is less difference, which shows that the intake effect of the combination is well.

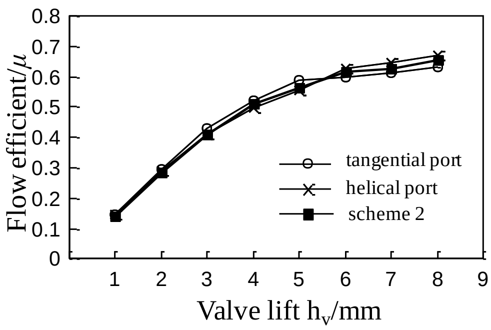


Fig. 4. Comparison of the flow coefficient between scheme 2 and single intake port.

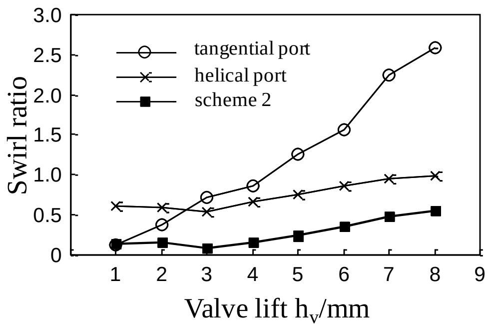


Fig. 5. Comparison of the swirl ratio between scheme 2 and single intake port.

As shown in Fig.5, in the range of full valve lift, the swirl ration of the schem2 is less than signal spiral port and signal tangential port, and its value is less than 0.5.And the swirl ratio is close to 0 when the valve lift is less than 4 mm; when the valve lift is greater than 4 mm, the swirl ratio of the signal spiral port and signal tangential port increases obviously, but to the scheme2, the swirl ratio is still a relatively small range of changes, and the reason is the mutual inference of the spiral and tangential port, and the swirl ration of the tangential port is offset and the offset effect is obvious.

3. Interference Analysis Method Of The Combine Intake Port

The relative flow coefficient μ_C and relative swirl ratio SR_C were used to evaluate the flow interference of the combine intake port (Chunhui *et al.* 2014; Jiaxiu *et al.*, 2000). If the ratio value is equal to 1, the intake air flow of the combine intake port does not generate interference; if the ratio value of deviate 1, which shows there is mutual interference in combine intake port, and the ration value of deviation from 1 is greater, the interference is greater. And the μ_C and SR_C are defined as follows:

The relative flow coefficient μ_C is calculated as follows:

$$\mu_C = \mu_{actual} / \mu_{theo} \tag{1}$$

The relative swirl ratio SR_C is calculated as follows:

$$SR_C = SR_{actual} / SR_{theo} \tag{2}$$

Where μ_{actual} and μ_{theo} are practical and theoretical flow coefficient, respectively; the SR_{actual} and SR_{theo} are practical and theoretical swirl ration, respectively.

4. Interference Analysis of The Combine Intake Port

The maximum valve lift of the diesel engine is 8mm, so in the process of the analysis, the valve lift was setted from 1mm, each interval is 1mm, and the relative flow coefficient and relative swirl ratio are simulated and analyzed.

4.1 Analysis of Relative flow Coefficient and Relative Swirl Ratio

As shown in Fig.6, the relative flow coefficient of the 4-scheme is in the range of 0.88 to1.08 and is unstable to 1, which indicates the interference exist in the adjacent ports of the combined intake ports in the intake process, and the airflow interference is not serious because of the deviation of the relative flow coefficient various range to 1 is small. When the valve lift is less than 5 mm, the relative flow coefficient of the 4-scheme is unstable, and there is great fluctuation; when the valve lift is greater than 5 mm, the relative flow coefficient curve of each combined intake ports is stale and gentle, and the relative flow coefficient of the scheme1 and scheme4 is close to 1. So according to the relative flow coefficient values, the interference influence order is: scheme4<scheme1 <scheme2<scheme3. The scheme3's relative flow coefficient value is the minimum, which is 0.88 and shows the interference effect of the helical combined intake port is the most significant.

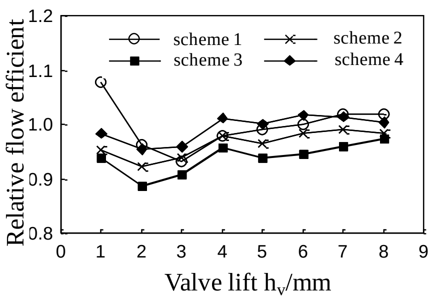


Fig. 6. Relationship between the relative flow coefficient and valve lift.

As shown in Fig.7, the relative flow swirl ratio value of the 4-scheme is also less than 0.5, which shows that the two strands inference swirl of direct collision and energy weakens is generated at the region between the two inlet valves and the cylinder top face. The relative flow swirl ratio value of scheme 1 is greater than other three schemes, which shows that the interference effect is less than other three schemes, and when the valve lift is 1mm and 8mm, the swirl ratio values are 0.32 and 0.23 respectively, and the swirl ratio fluctuates between 0.35 and 0.45 with other valve lifts. The relative flow swirl ratio value of the scheme 4 is close to 0 when the valve lift $h_v \leq 5$ mm, which shows that the

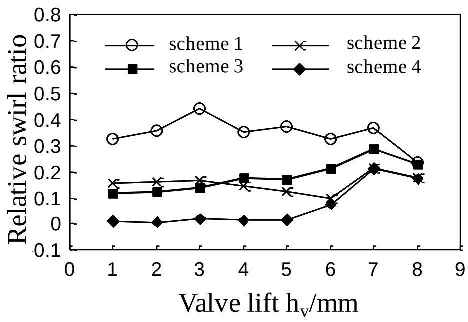


Fig. 7. Relationship between the relative swirl ratio and valve lift.

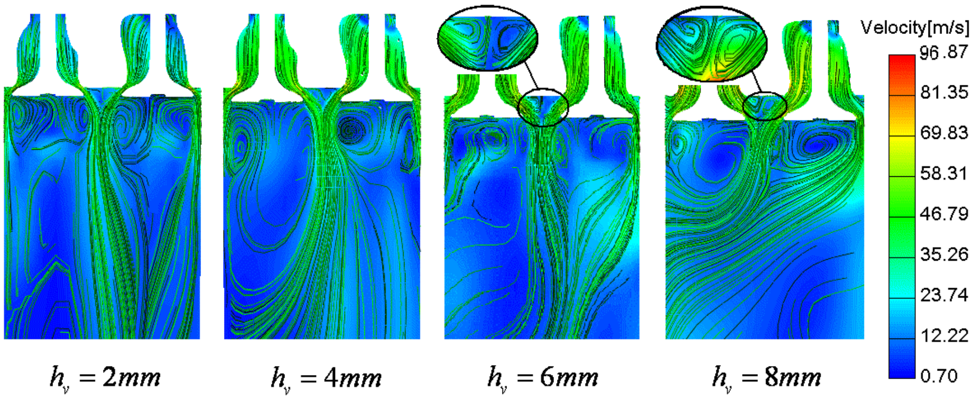


Fig. 8. Gas inference of adjacent intake port in the Scheme1.

flow inference is serous; and the flow inference is reduced when the valve lift h_v>5 mm, and the maximum relative flow swirl ratio value is 0.2 when the valve lift is 7 mm.

4.2 Flow Inference Analysis of Intake Air Flow Field

In order to intuitive analyze the intake flow inference of the adjacent port in the combined intake ports, the CFD simulation results of the center section of the two inlet valve were analyzed with the valve lift is 2, 4, 6, and 8 mm.

（1）Scheme1 (combination of left helical port and right tangential port)

As shown in Fig.8, the maximum gas flow rate is 95.6 m/s when the valve lift is 2 mm, the reason is that the circulation section area between the valve and valve seat is the smallest and the pressure difference of between cylinder and intake port is maximum. The gas in the area of the adjacent intake port collision and extrusion, and most of the gas moves along the center line of the cylinder to the cylinder bottom; a small part of the gas converges in the vicinity of the cylinder head and two and new small scale gas turbulence is formed, which causes the intake inference and reduces the air flow in the cylinder, and this phenomenon is more obvious when the valve lift is respectively 6mm and 8mm. Most of the gas in the cylinder generates reflow after touching the cylinder wall and the swirl of significant different in size converges below the valve, at last, the two large swirl is converged at the just below area of the valve with valve lift increases.

（2）Scheme2 (combination of left tangential port and right helical port)

As shown in Fig.9, the maximum gas flow rates are 91.8 m/s and 88.4 m/s when the valve lifts are respectively 2 mm and 8 mm. A small part of air generates inference at the adjacent area of the two intake ports, and small swirl forms in the vicinity of the cylinder head, which has the blocking effect and reduces the amount of the air into the cylinder. The gas into the cylinder along the cylinder wall moves along the cylinder wall, which converges with the gas along the cylinder center line and move to the cylinder bottom, at last, four large swirls are formed below the valve with valve lift increases.

（3）Scheme3 (combination of left tangential port and right tangential port)

As shown in Fig.10, the maximum gas flow rates is 92.4 m/s when the valve lift is 2mm, the maximum gas flow rates are 84.4 m/s、84.3 m/s and 84 m/s when the valve lifts are respectively 4mm、6mm and 8mm.The gas flow rates show that although the gas circulation area becomes larger, but the maximum gas rates has little change near the valve seat, the interference of adjacent ports is corresponding to the valve lift range.

（4）Scheme4 (combination of left tangential port and right tangential port)

As shown in Fig.11, the maximum gas flow rates are 94.6 m/s、89.6 m/s、89.3 m/s and 83.7 m/s

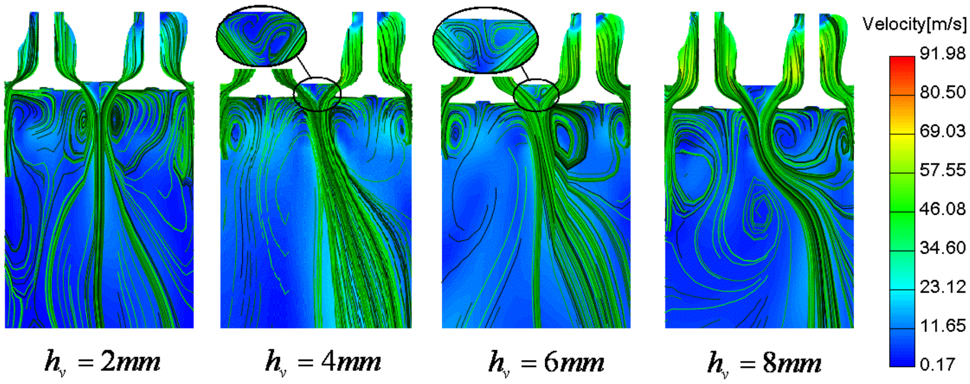


Fig. 9. Gas inference of adjacent intake port in the Scheme2.

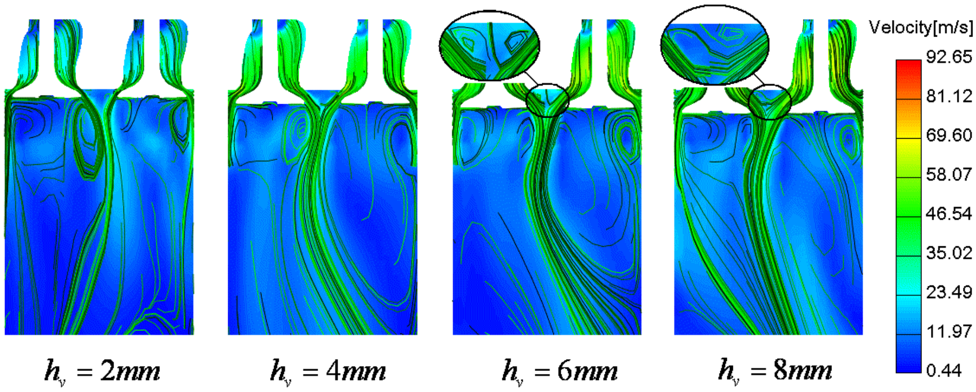


Fig. 10. Gas inference of adjacent intake port in the Scheme3.

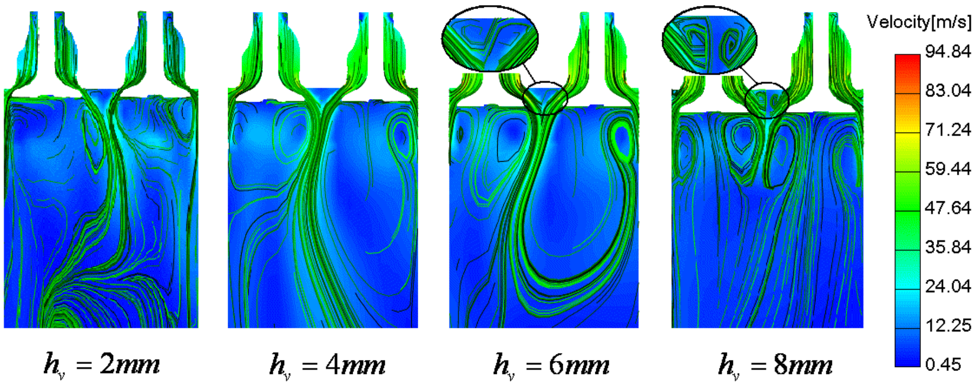


Fig. 10. Gas inference of adjacent intake port in the Scheme4.

when the valve lifts are respectively 2、4、6 and 8 mm, which show that the maximum gas rates decreases with the valve lift and circulation area increase, and its range drops a little. At the maximum valve lift, the gas in the adjacent areas of the two intake ports generates interference and two irregular swirls are formed, which has negative effect on the intake air.

5. CONCLUSIONS

This work investigated the flow interference of the combined intake ports by 3D fluid simulation model and steady-state experiment. Each combined intake port has its own flow rule, but there are some common rules on the four combined intake ports.

(1) The relative flow coefficient and swirl ratio can directly reflect the intake flow interference of the combined intake ports, and the value is close to 1, which indicates that the interference is small; the value is close to 0, which indicates that the interference is serious.

(2) The combined intake ports have not obvious effect to relative flow coefficient, but have obvious effect to relative swirl ratio.

(3) The mutual interference of the adjacent intake

ports is obvious when the valve lift is low valve lift, and the swirl is formed strongly in the cylinder with the valve lift increases.

(4) In the future, the flow field influence of combined intake ports to in-cylinder should be analyzed, and the airflow velocity and turbulent kinetic energy rules of the air changes with different valve lifts may be mastered.

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