Steady flow test and numerical simulation of a GDI engine

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Abstract. In this paper, steady flow tests for air movement characteristics in cylinder and intake port flow coefficient of a GDI engine were carried out by means of steady flow test bench. Three-dimension numerical simulation model was established with consistent boundary conditions of steady flow tests. Experiment results indicated that tumble was the main air flow of this GDI engine. Intake port flow coefficient measured during tumble tests were lower than that of swirl tests, and as intake valves raised the difference between those two tests was more and more obvious. Simulation results were almost identical with experiment date. The in-cylinder velocity field and pressure field demonstrated that the structure of dummy cylinder in steady flow tests had a great influence on in-cylinder air flow. In tumble tests, air flow in dummy cylinder were turned back to intake valves and a part of intake air were pushed by the turned back flow. A sector of low speed and high back pressure area could be found near by intake valves. Such air flow impact was believed as the reason of such difference on intake port flow coefficient.

Introduction

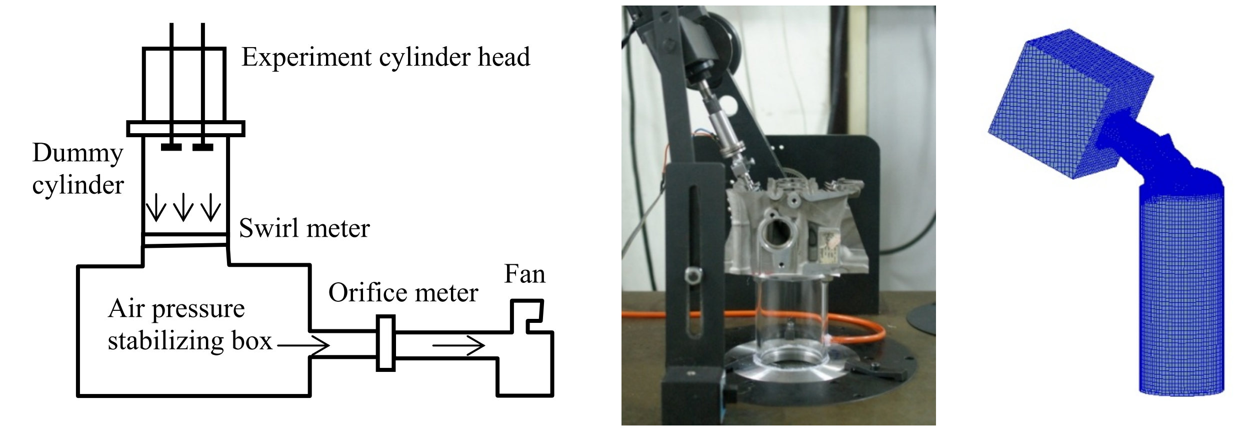
Gasoline direct injection (GDI) engine has significant advantages and potential in fuel economy, output power and transient response, which represents the developing direction of the engine at present. The quality and stability of air-fuel mixture decide the engine performance in wide speed range [1]. For a GDI engine, intake port plays a pivotal role in air-fuel mixing process.

In this paper, a series steady flow tests for air movement characteristics in cylinder and intake port flow coefficient of a GDI engine were carried out by means of steady flow test bench. Testing results showed that tumble is the mainstream in in-cylinder, and difference of flow coefficient could be found at high valve lift between swirl tests and tumble tests. In order to make clear the detailed information about air flow, three-dimension numerical simulation model was established with consistent boundary conditions of steady flow tests. The simulated results were similar to experiment date and indicated that different dummy cylinders in steady flow tests had great influence on intake port flow coefficient.

Steady flow tests

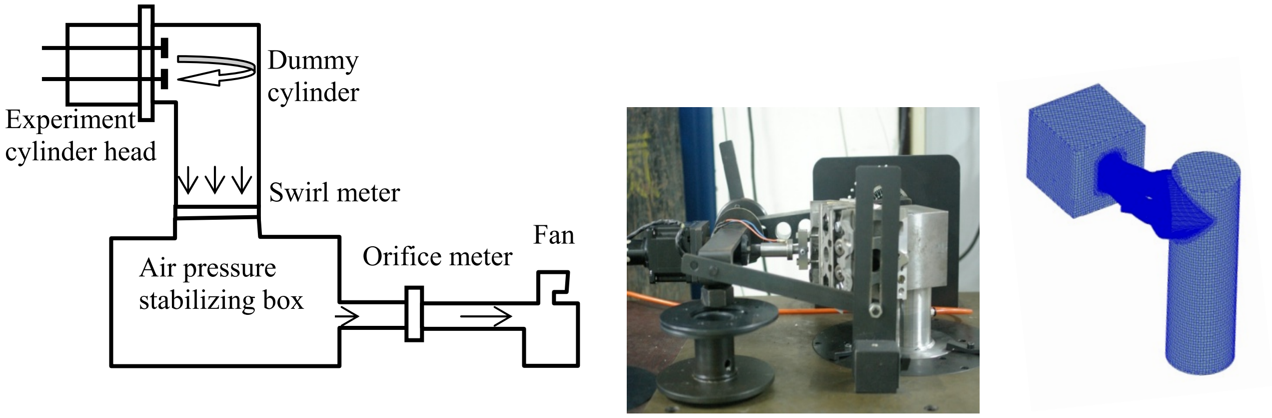
Evaluation testing methods. Steady flow test is a valuable method to evaluate performance of engine intake port. There are four mainstream methods, Ricardo method, AVL method, FEV method and SWRI method [2]. In this paper, Ricardo method was selected. Ricardo dimensionless flow coefficient is the rate of the actual air flow rate though the valve seat to the theoretical air flow rate. Ricardo dimensionless swirl strength Nr is the rate of the in-cylinder tumble velocity to the engine crank shaft speed in every valve lift.

Steady flow test bench with impulse swirl meter. The principle of this steady flow test bench was law of conservation of angular momentum. Swirl meter could measure the angular momentum of in-cylinder air flow, then to calculate swirl strength result. So the dummy cylinder was different when to measure tumble strength. Diagrams and photographs of swirl and tumble test were showed in Fig. 1 and Fig. 2.



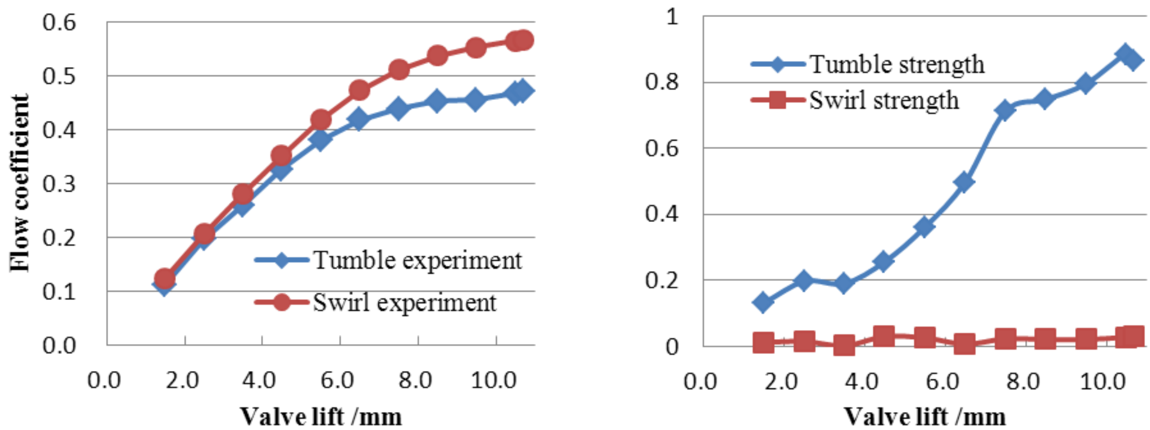
(a) Diagram of swirl test (b) Photograph of swirl test (c) Simulation model

Fig. 1 Diagram, photograph and simulation model of swirl test



(a) Diagram of tumble test (b) Photograph of tumble test (c) Simulation model

Fig. 2 Diagram, photograph and simulation model of tumble test



(a) Flow coefficient of two experiment (b) Swirl strength and tumble strength

Fig. 3 Result of steady flow experiment

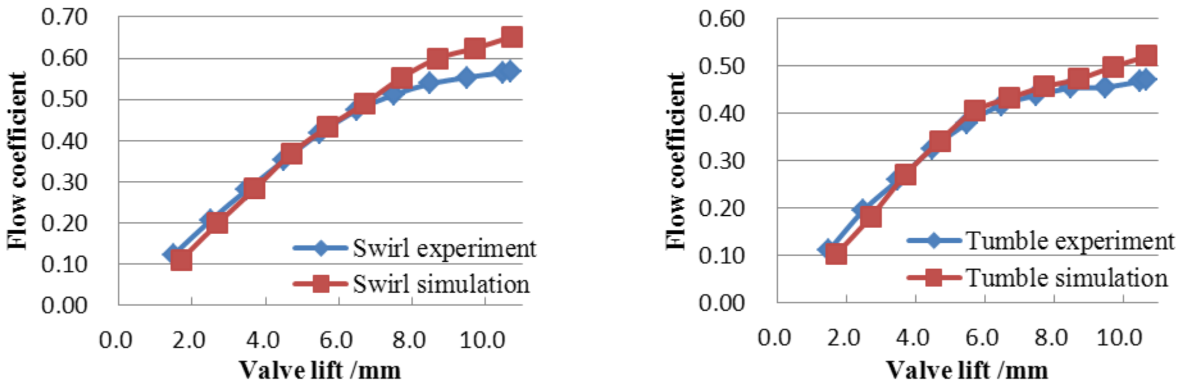
Experiment results. Fig. 3(a) indicated that the flow coefficient was different between tumble and swirl experiment, and repeated tests had confirmed it again. Fig. 3(b) indicated that the main air flow of this GDI engine cylinder head was tumble. Ricardo tumble strength was increased with valve lift becoming higher while Ricardo swirl strength was very low no matter with lift of intake valves.

Numerical simulation

Calculation meshes and models. In order to balance the mesh quality and quantity, the grid was divided into many areas to be meshed in various grid sizes. The total number of grid cells was about

600,000 to 900,000. Boundary conditions were as same as that of experiments. Inlet pressure was 100,000 Pa and outlet pressure was 92,500 Pa (valve left < 3mm) or 96500 Pa (valve left ≥ 3mm). Turbulence model was K-zeta-f model. Fig. 1(c) and Fig. 2(c) showed the typical meshes of swirl test and tumble test.

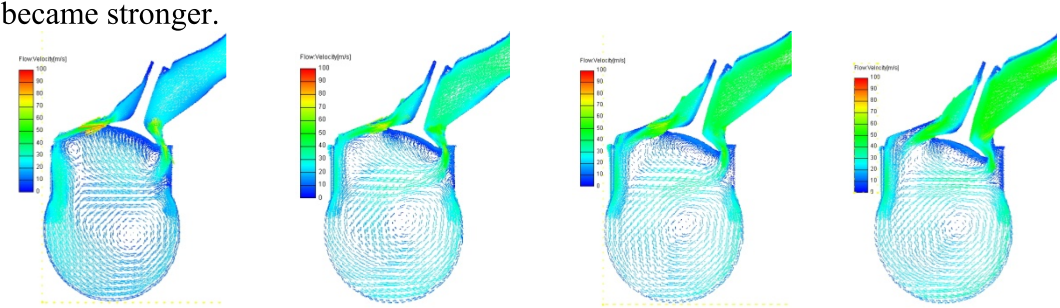
Simulation results. Fig. 4 indicated that the flow coefficient of both swirl and tumble tests were well consistent between numerical simulation and experiment data. Simulation results also indicated that flow coefficient in swirl model was higher than that in tumble model.



(a) Swirl test (b) Tumble test

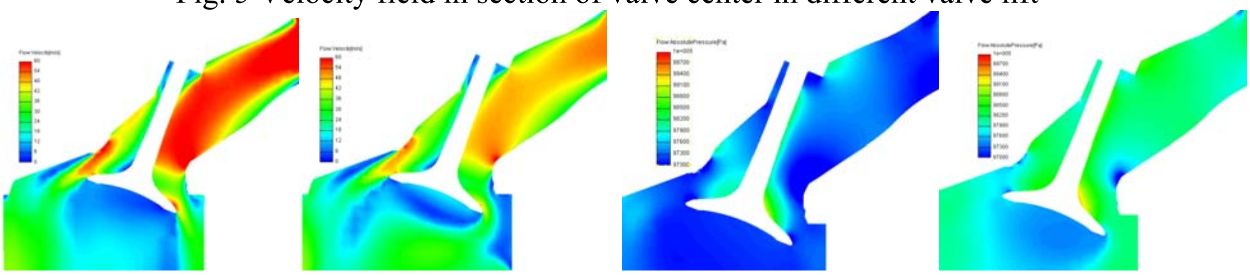
Fig. 4 Simulation results and experiment results

Fig. 5 showed the in-cylinder velocity field in section of valve center at different valve lift. The structure of dummy cylinder helped to form a large anticlockwise tumble. The high speed air flow though valve seat made a small clockwise tumble under the valve. As valve lift increased, both two tumbles became stronger.



3.7mm 5.7mm 7.7mm 10.7mm

Fig. 5 Velocity field in section of valve center in different valve lift



(a) Velocity field of swirl model (left) and tumble model (right)

(b) Pressure field of swirl model (left) and tumble model (right)

Fig. 6 Velocity and pressure field between swirl and tumble models at 10.7mm valve lift

Fig. 6(a) indicated that velocity of intake port air flow in swirl model was much faster than that in tumble model. There was a sector of low speed near valve seats in the velocity field of tumble model, because two tumbles impacted each other at that section. Fig. 6(b) indicated that although differential pressures of both two models were equal to each other, the differential pressures between air inlet face and valve seats were different. Furthermore, intake port pressure in swirl model was much lower than that in tumble model. The in-cylinder velocity field and pressure field demonstrated that the structure of dummy cylinder in steady flow tests had a great influence on in-cylinder air flow. In tumble tests, air flow in dummy cylinder were turned back to intake valves and a part of intake air were pushed by the turned back flow. A sector of low speed and high back pressure could be found near the intake valves in tumble model. Such air flow impact was believed as the reason of such difference on intake port flow coefficient.

Summary

1) A GDI engine cylinder head was selected for this paper. Steady flow tests for air movement characteristics in cylinder and intake port flow coefficient tests and 3D CFD simulation were carried out and compared.

2) Numerical simulated results were almost identical with experimental data and numerical simulation model was provided with preferable accuracy and practicability.

3) Both steady flow tests and numerical simulation demonstrated this GDI engine intake port could promote strong tumble in cylinder but there was obvious difference in measuring flow coefficient between swirl tests and tumble tests.

4) In tumble tests, CFD simulation showed that air flow in dummy cylinder were turned back to intake valves and a part of intake air were pushed by the turned back flow. A section of low speed and high back pressure could be found near the intake valves. Such air flow impact was believed as the reason of such difference on intake port flow coefficient between swirl tests and tumble tests.

5) To evaluate different cylinder heads by flow coefficient, it is necessary to make sure that the structures of dummy cylinders were the same form (swirl or tumble).

References

[1] R.V. Basshuysen: Gasoline Engine with Direct Injection (Vieweg+Teubner Publications, Germany 2009).

[2] ZHAO Zhen-wu, LIU Shu-liang: Study on the test technology of steady state flow of port with variable pressure drop. Transactions of CSICE. Forum Vol. 22 (2004), p. 79-85.

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