Study of Intake swirl in 4 cylinder 4 valve cylinder head using Experimental and CFD Analysis

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Abstract: In an IC Engine the performance, efficiency and emission depends on the formation of air-fuel mixture inside the engine cylinder. The main objective of this study is to investigate the technique to optimize the air swirl to achieve better engine performance and emission in a direct injection 4 cylinder 4 valve cylinder head of diesel engine. The objective of present study is to predict and analyze the flow through intake manifold and inlet port system using Computational Fluid Dynamics (CFD) and to validate the prediction by experimental data. Three dimensional model of the intake port with and without manifold is created in CREO and this model of air intake system was analyzed by using the commercially available AVL FIRE software. The results indicate that the CFD model can be used as a tool to understand the effect of various parts of air intake system for optimization.

***IndexTerms* – Swirl, Flow Coefficient, Cylinder Head, CFD, AVL FIRE, Diesel Engine, Intake Port, Intake Manifold**

I. INTRODUCTION

Swirl is the rotation of charge about cylinder axis and it is used in SI engines to speed up the combustion process and in the diesel engines to control the air fuel mixing. However, too much turbulence leads to excessive heat transfer from the gases to cylinder walls and may create problems of flame propagation. Optimum swirl can be created by the optimum design of the intake port. High swirl is also not desired, as the kinetic energy for the flow is obtained at the expense of a reduced volumetric efficiency. It would be desirable to control swirl to meet conflicting engine operation requirements. Engine efficiency, power output, noise, vibrations and emissions are all impacted by the strength of swirl of gases in an engine's cylinders [2].

Swirl nature is difficult to determine, so steady state tests are performed to determine swirl. Generally light paddle wheel is used to measure rotation of paddle wheel as a measure of air swirl. Rotation rate depends on location, design and details of swirling flow. Swirl is measured in terms of Swirl number or Swirl ratio.

II. LITERATURE SURVEY

There are 2 kinds of designs commonly used; these are the directed port and the helical port. Helical ports normally have a higher discharge coefficient and volumetric efficiency than directed ports if the swirl levels are equivalent. Also, a helical port produces better swirl than a directed port since they impart more angular momentum than directed ports [1]. The key factor in generating a high swirl ratio is to suitably control the direction of the intake air flow through the valve seat. Helical port for generates an ultra-high swirl ratio and the other port is a tangential port which generates a low swirl ratio. It indicates that the total performance of both ports can be estimated from the performance of a single port [5].

There are different methods for investigation of air swirl. In which Different Lifts method is an effective method in swirl induction. Different Lifts mechanism, acting on the valve curtain area, is more effective in flow unbalancing between intake ports, since the flow rate depends linearly on the curtain area [4].

There are other methods for improving swirl as shrouding of an Inlet valves[3], providing fins, grooves and masking on an Inlet valve[6], [8], [9]. There are some methods for improving swirl as changing manifold configurations as helical, spiral and other combinations of them[10], [11].

CFD analysis is performed for validation of experimental results. CFD analysis is a better option to carry out repetitive parameter studies with change in boundary conditions in order to investigate various configurations and flow patterns[3], [7], [12].

III. METHODOLOGY

Literature survey is done to investigate different methods used to obtain optimum swirl ratio. The experimental readings are taken on 4 cylinder 4 valve cylinder head with and without manifold to calculate Swirl ratio and these results are compared with CFD results which are obtained in AVL FIRE software. The modifications are done in 3 D model to obtain optimum Swirl ratio then these modifications are done in actual cylinder head with manifold. After that the testing is done with manifold to get the results similar as that of actual engine. These results are compared and validated.

IV. Experimental Setup

AVL swirl test rig has been used to determine the swirl number and flow coefficient. The measurement of swirl number and mean flow coefficient is taken on the steady state flow test rig. The flow parameters are determined using paddle wheel anemometer for RPM measurement, flow sensor for air flow measurement and U tube manometer for Pressure drop measurement as shown in figure. Air is sucked by the blower through the intake port, over the valve, cylinder liner and surge tank as shown in fig. 1. This creates a vacuum below the valve which creates suction of air through intake port. The exhaust is blown out by blower.

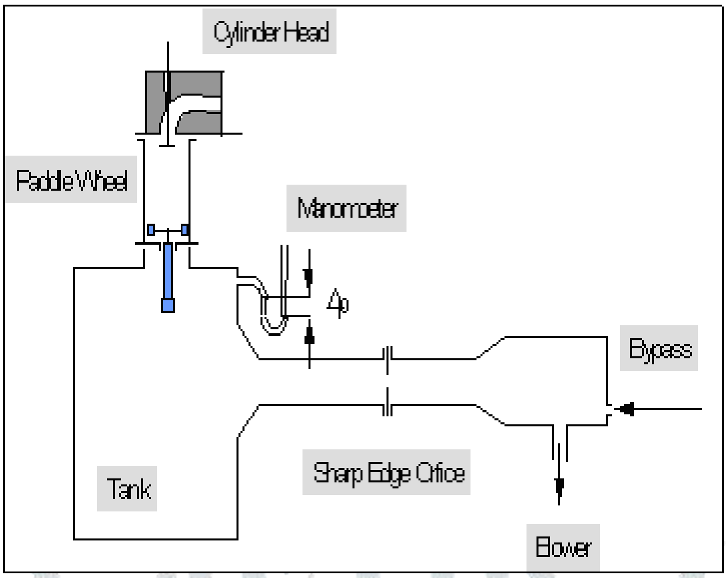

Fig 1 Experimental Setup

The Intake port of cylinder head without manifold and with manifold are considered for experimental readings. The Intake port with manifold is simulated since in actual engine there are restrictions for air flow due to intake manifold. The readings are taken for each valve lift from 0 mm to 13 mm. The experimental readings are given as an Input to obtain Average Flow Coefficient, Average Swirl Number and Reduced Mean Swirl Number.

Equations

From Experimental data of tank pressure, air flow rate and paddle wheel speed of certain valve lift we can calculate Flow coefficient, Swirl Number for that valve lift. From data of Flow Coefficient and Swirl Number we can calculate Average Flow Coefficient and Average Swirl Number by using Simpsons rule. Equation (1) and (2) are formulae for Calculation of Flow Coefficient and Swirl Number.

- Flow Coefficient = $\frac{\text{Gact}}{\text{Gth}}$ (1)
- Swirl Number = $\frac{\text{Nd}}{\text{N}} = \frac{\text{Nd}}{\text{Gact}} \times \frac{\rho\,\text{A S}}{30}$ (2)

Where, Gact = Actual mass flow rate
Gth = Theorotical mass flow rate
Nd = Paddle wheel speed
N = Engine speed
ρ = Density of air
A = Area of cylinder
S = Stroke
D = Bore diameter

V. CFD ANALYSIS

The three dimensional model including Intake Port, Cylinder, Valve and valve seat is imported. The Surface mesh and Edge mesh is created to create volume mesh. The meshing size is given very finer for valve and valve seat. The meshing is checked against many errors. The meshing is improved with refinement and by removing bad cells in various aspects. The boundaries are defined after meshing.

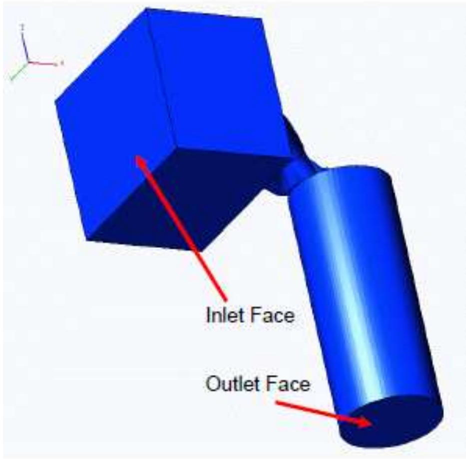

Fig 2 Intake Port Model for Simulation

Steady state simulation is run with clearly defined boundary conditions, fluid properties and initial conditions. With appropriate discretization method, differencing scheme, linear solver and engine specifications such as bore, stroke, valve seat diameter and connecting rod length the calculation is run to meet certain convergence criteria.

The results are obtained as flow velocity, pressure and other parameters contours in post processing. The graphs are plotted of residuals, Flow coefficient and Swirl Number.

Intake port without manifold is simulated first for 4 valve lifts as 3 mm, 6 mm, 9 mm and 13 mm. 13mm valve lift is taken as maximum valve lift Since after 13 mm valve lift the results are nearly similar. The Swirl ratio and Flow Coefficients can be taken as zero for 0 mm valve lift neglecting leakages. The flow can be observed at various valve lifts for Intake port without manifold with pressure and velocity contours. The CFD results are plotted as follows.

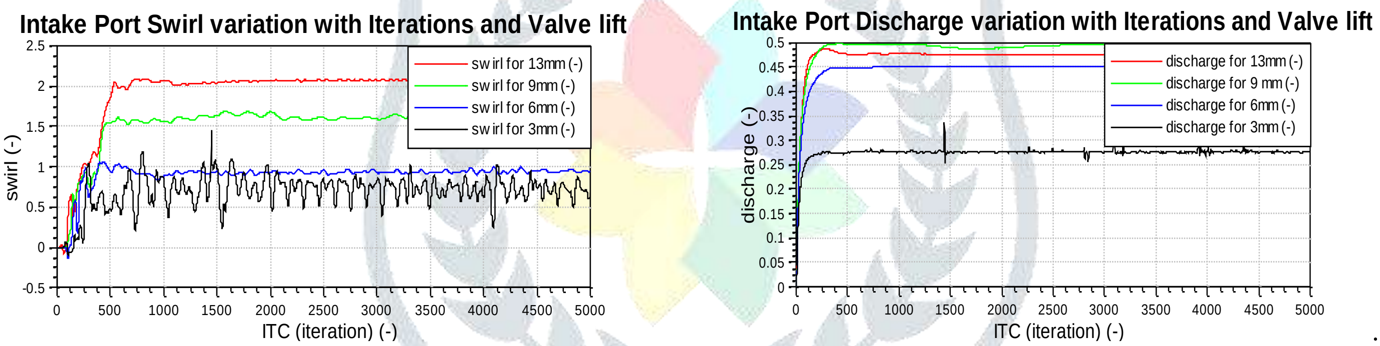

Fig 3 Post processing result for Swirl and Discharge of Intake port swirl variation with iterations and valve lift

The Swirl ratio and Flow coefficient for other intermediate valve lifts can be found out by using Interpolation. Then this data is used to find out Average Flow Coefficient, Average Swirl Number and Reduced mean Swirl Number by using Simpsons rule.

The similar methodology is used for the simulation of Intake port with manifold in which there are four intake ports connected to intake manifold simultaneously one port at a time. The Intake port with manifold is simulated since in actual engine there are restrictions for air flow due to intake manifold. So it is important to do analysis of each intake port of a cylinder head with manifold. One Port at a time is analyzed with manifold.

VI. RESULTS AND DISCUSSION

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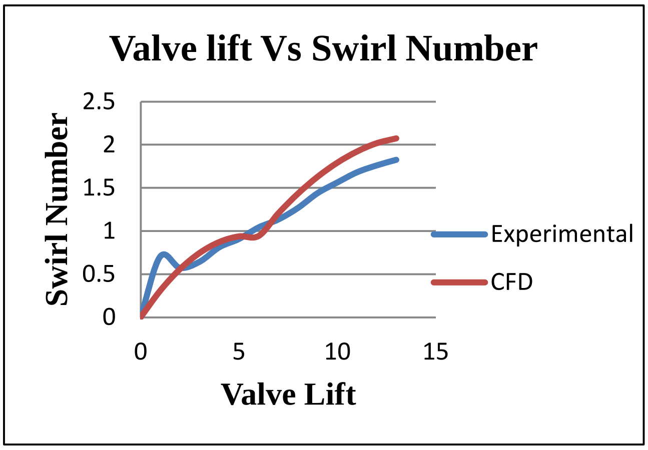
The experimental and CFD results are compared for validation in tabular as well as graphical form.

A. For Intake Port

The experimental and CFD results are compared for validation in graphical and tabular format for Intake port without manifold.



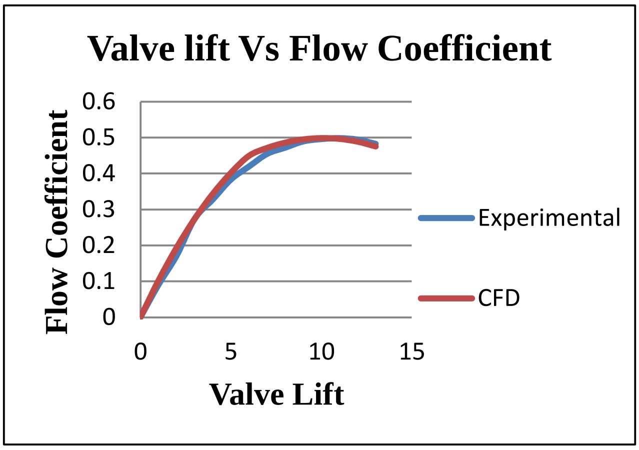


Fig. 4 Comparison of Experimental and CFD Analysis for Port without manifold

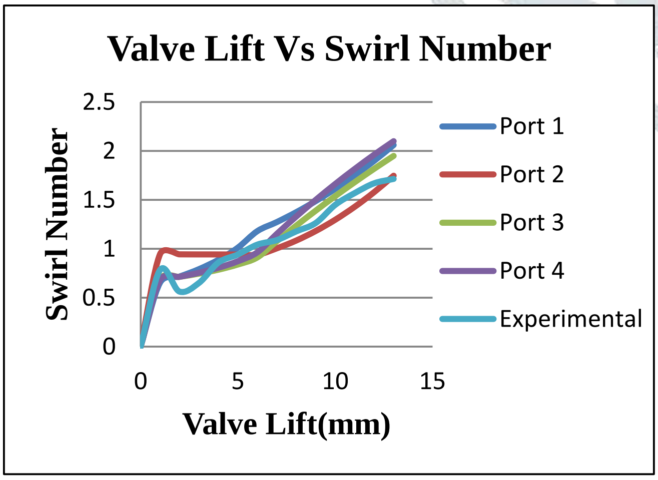
Table 1 Comparison of Experimental and CFD results for Intake Port with manifold

	Results		
Analysis Type	**Average Flow Coefficient**	**Average Swirl Number**	**Reduced Mean Swirl Number**
Experimental	0.3372	1.60	1.41
CFD	0.3481	1.67	1.47

From the graphs and table above of experimental and CFD analysis results we can see that there is very small difference in results of them. So Intake port is validated against experimental and CFD analysis with an acceptable error.

B. For Intake Port with manifold

The experimental and CFD results are compared for validation in graphical format for Intake port without manifold. Only one port is considered for experimental evaluation with manifold. Since Intake port without manifold is validated and by considering less variation in results of Experimental data CFD analysis can be done for evaluation of swirl and discharge for other ports. The CFD analysis of 4 ports is done to validate the results with experimental result.



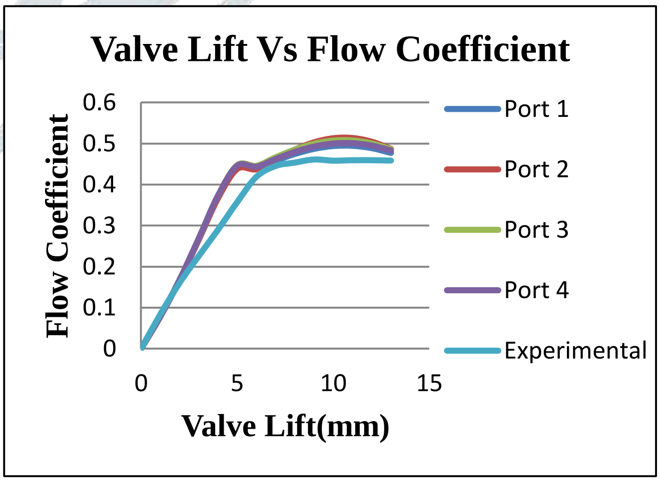


Fig. 5 Comparison of Experimental and CFD Analysis for Port with manifold

Table 2 Comparison of Experimental and CFD results for Intake Port with manifold

Analysis Type	Results		
	Average Flow Coefficient	**Average Swirl Number**	**Reduced Mean Swirl Number**
Experimental	0.3195	1.50	1.32
CFD for Port 1	0.3325	1.65	1.45
CFD for Port 2	0.3475	1.51	1.33
CFD for Port 3	0.3487	1.55	1.37
CFD for Port 4	0.3445	1.63	1.44

VII. CONCLUSION

1) Experimental and CFD results are validated for Intake Port without manifold
2) By considering one port result of Experimental data CFD analysis for 4 ports can be done to get the results with manifold. Hence CFD and Experimental results are validated within acceptable variation.
3) The Intake manifold can be designed by considering swirl and discharge by considering same input to all 4 Intake Ports in case of 4k4v cylinder head.
4) CFD simulation can be effectively used as a tool for modifications either in port or manifold in future.

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