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Swirl Ratio and Mean Flow Coefficient within S.I. Engine Using Shrouded Intake Valve and Correlation Equations for Its Prediction

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Abstract:
In spark ignition engine, reduce in fuel consumption and exhaust emissions can be achieved by implementation of lean burn strategy by integrating swirl motion in the working fluid of the engine. Intake generated swirling flow can be produced by the use of shrouded intake valve. The advantage of using the shrouded intake valve is that it can be manufactured at ease, and it allows finding the appropriate level of swirl by turning the valve about its axis; however, it provides larger restriction to the incoming fluid. In this backdrop an experimental study has been conducted which highlight the variation of swirl ratio and mean flow coefficient within a spark ignition (SI) engine using shrouded intake valve of different shroud angle. The results obtained from the study show that the percentage variation of swirl ratio and mean flow coefficient within an SI engine on varying the shroud angle of a shrouded intake valve, is not affected by test pressure drop. Finally, in this study, correlation equations are proposed for prediction of swirl ratio and mean flow coefficient within an SI engine using shrouded intake valve of any degree of shroud angle.

1. Introduction

Lean burn strategy is a recently developed method to reduce emissions and fuel consumption in a spark ignition (SI) engine [1, 2]. However, on adoption of lean burn technique, the flame speed of the combustion process in an SI engine decreases significantly. The increase of the combustion duration due to the implementation of lean burn strategy can be reduced by enhancing turbulence within the working fluid of an SI engine. This leads to the increase in the acceleration of flame speed [3]. The turbulent intensity of the working fluid in an SI engine can be increased at the end of the compression stroke by inducing intake generated in-cylinder swirl flow [4].

Intake generated in-cylinder swirl flow is a structured rotation in the horizontal plane of an engine cylinder, which can be created by using a shrouded intake valve [5-7]. The main advantage of using a shrouded intake valve is that it can be manufactured with ease, and it permits to find the desired level of swirl ratio by only varying the shroud angle of a shrouded intake valve. However, the real disadvantage is that for generating a high degree of swirl, a shrouded intake valve of greater shroud angle is required. This results in substantial reduction in mean flow coefficient of an engine and as a consequence of it, the volumetric efficiency of an engine decreases.

The swirl development phenomenon within SI engines using shrouded intake valve has been studied by many researchers [6-9]. However, no study has been conducted to underline the nature of swirl ratio and mean flow coefficient variation within SI engines for the change in shroud angle of a shrouded intake valve in detail. Therefore, in this paper, a study has been carried out to determine the variation of swirl ratio and mean flow coefficient within SI engines on varying the shroud angle of a shrouded intake valve. Moreover, correlation equations are developed to predict swirl ratio and mean flow coefficient within an SI engine using shrouded intake valve of any degree of shroud angle.

2. Experimental Technique

In this study, steady flow test technique has been used for the purpose of experimentation. The main advantage of using steady flow test method is that it is less expensive, rapid and it provides output in the form of flow coefficient and swirl coefficient, which is easily understandable. But, the main disadvantage of this technique is that it does not give a detail information about the in-cylinder flow structure. However, in spite of its weakness, there is adequate proof that steady flow tests relate well to the actual engine performance [10]. Therefore, in this present study, a steady flow test has been carried out.

3. Experimental Setup

The schematic diagram of the experimental setup used in this study is shown in Figure 1(a). The experimental setup consists of engine head placed over a dummy cylinder having a diameter equal to the engine bore (B) and a paddle wheel swirl meter for measuring the swirl within the dummy cylinder, located at 1.75B on the downstream of the engine head [11]. The complete setup is then positioned above the Super flow test bench for suction of air, which is capable of maintaining a maximum pressure drop of 14.95 kPa across an engine head. Finally, the paddle wheel swirl meter and the Super flow bench are connected to a computer for data acquisition through the USB ports. In the experimental setup, before data acquisition, the paddle wheel swirl is calibrated by use of a known reference swirl as explain in Heim and Gandhi [12].

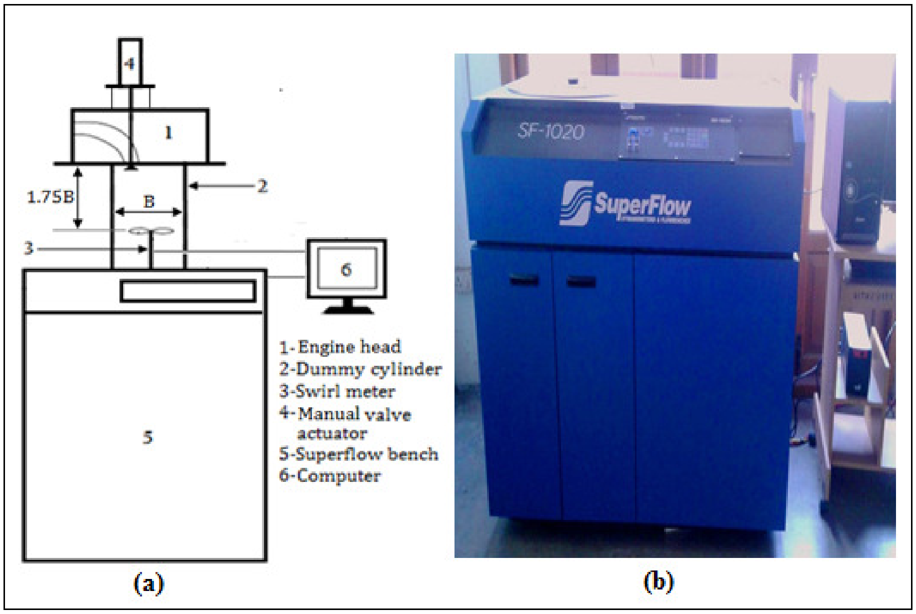

Figure 1: (a) Schematics of experimental setup (b) Photographic view of experimental setup

4. Description of Cases

In this experimental study, three different type of engine heads are used, whose main specifications are given in table 1. In each engine head, shrouded intake valve with shroud angle (α) of 40^0, 60^0, 80^0, 100^0, 120^0, 140^0, 160^0 and 180^0 are used. The shroud height of each valve is kept equal to the maximum lift of the intake valve in the engine head in which it is used. A generalized schematic diagram of a shrouded intake valve is shown in Figure 2(b).

Engine Head	Head 1	Head 2	Head 3
Bore x Stroke (mm)	68 x 45	86 x 86	87.5 x 110
Number of intake valve	1	2	2
Intake valve diameter (mm)	26	28	30
Seat angle (degree)	45	44.5	45
Inclination (degree)	0	26	0
Maximum lift of intake valve (mm)	6.5	7	7.5
Intake valve opening duration (degree)	230	224	246

Table 1: Main specification of the engine heads.

5. Measuring Parameter

The restrictions to the flow offered by the intake valves are characterized by flow coefficient and mean flow coefficient [3, 13, 14]. Flow coefficient is defined as the measure of actual mass flow rate to theoretical mass flow rate and is given by

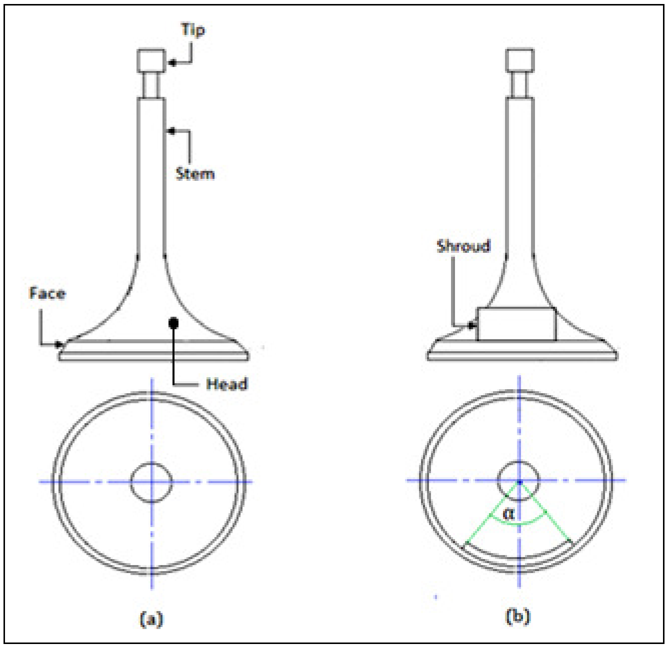

Figure 2: (a) Schematics of poppet intake valve (b) Schematics of shrouded intake valve

$$C_f = \frac{\dot{m}}{\rho V_B A_V} \tag{1}$$

where, the Bernoulli velocity is given by

$$V_B = \sqrt{\frac{2\Delta P}{\rho}} \tag{2}$$

and the representative area is given by

$$A_V = \frac{\pi}{4} i D_V \tag{3}$$

Mean flow coefficient is the average of flow coefficient over the crank angle between intake valve opening and intake valve closing and is given by

$$C_{f(mean)} = \frac{\int_{\theta_{IVO}}^{\theta_{IVC}} C_f d\theta}{(\theta_{IVC} - \theta_{IVO})} \tag{4}$$

Swirl generated by the intake valves are characterized by swirl coefficient and swirl ratio [4, 14, 15]. Swirl coefficient is defined as the ratio of angular momentum of flow with its axial momentum and is given by

$$C_s = \frac{\omega_s B}{V_B} \tag{5}$$

Swirl ratio as a global swirl generation parameter for the entire intake process of the engine is defined as

$$R_S = \frac{BS\int_{\theta_{IVO}}^{\theta_{IVC}} C_f C_S d\theta}{iD_V^2 (\int_{\theta_{IVO}}^{\theta_{IVC}} C_f d\theta)^2} \tag{6}$$

6. Result and Discussion

Steady flow tests are performed to determine the variation of swirl ratio and mean flow coefficient within SI engines on varying the shroud angle of a shrouded intake valve. The tests are carried out at ΔP = 7.5kPa and 9.5 kPa to ensure that the flow of fluid is at fully turbulent condition so that the loss of velocity head becomes independent of the pressure drop or flow rate [10]. Moreover, it is seen that at such pressure drop, the incompressible relation for velocity is sufficient [10]. Finally, the obtained experimental results are analyzed and presented in this section.

6.1. Mean Flow Coefficient

Figure 3 shows the mean flow coefficient of all the considered engine heads with different shrouded intake valve at ΔP = 7.5kPa and 9.5 kPa. Flow coefficients for non-dimensional valve lift (L_V/D_V) of 0.05, 0.1, 0.15, 0.2, and 0.25 are used for determining the mean flow coefficient for all the considered cases in the study. Flow coefficient for any of the non-dimensional valve lift is calculated as per Eq. (1) by making use of the air mass flow rate obtained from the experiment.

From Figure 3, it can also be seen that the mean flow coefficient of all the considered engine heads has decreased on using shrouded intake valve of higher shroud angle. It emphasizes the fact that an SI engine with shrouded intake valve of larger shroud angle provides a greater restriction to the incoming fluid flow.

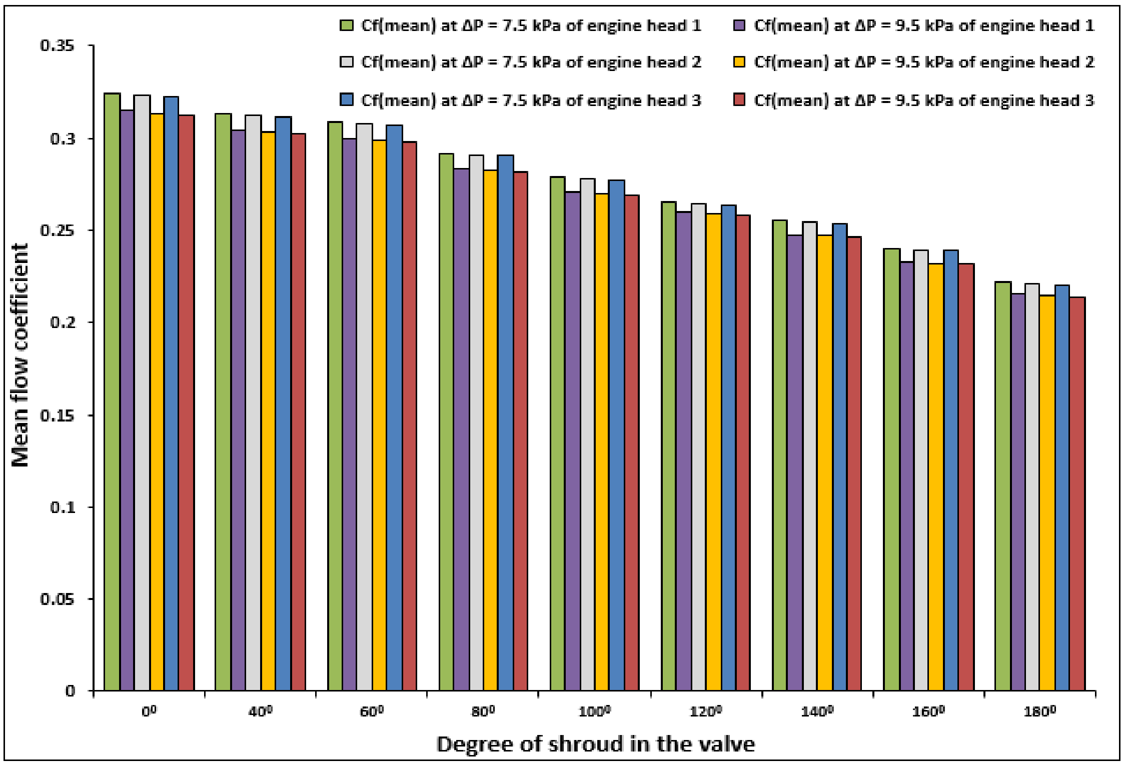

Figure 3: Mean flow coefficient of the engine heads.

6.2. Swirl Ratio

Figure 4 shows the swirl ratio of all the considered engine heads with different shrouded intake valve at ΔP = 7.5kPa and 9.5 kPa. Swirl coefficients and flow coefficients for non-dimensional valve lift (L_V/D_V) of 0.05, 0.1, 0.15, 0.2, and 0.25 are used for determining the swirl ratio for all the considered cases in the study. Swirl coefficient for any of the non-dimensional valve lift is calculated as per Eq. (5) by making use of the paddle wheel angular velocity obtained from the experiment.

From Figure 4, it can also be seen that the swirl ratio of all the considered engine heads has increased on using shrouded intake valve of higher shroud angle. This highlight the fact that an SI engine with shrouded intake valve of higher shroud angle generates a high level of swirl flow

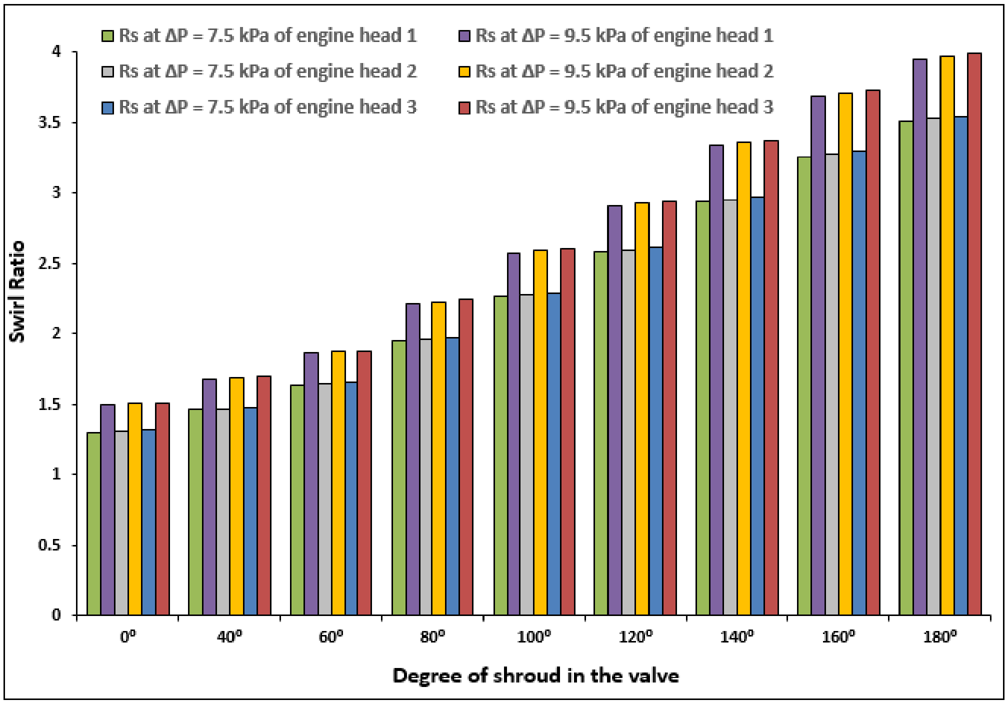

Figure 4: Swirl ratio of the engine heads.

6.3. Variation of Mean Flow Coefficient and swirl Ratio

Figs. 5(a) and 5(b) show the percentage variation of mean flow coefficient and swirl ratio of the SI engines with the considered shrouded intake valve compare with the same engines using poppet intake valve. It is seen from Figs. 5(a) and 5(b) that the percentage increase in swirl ratio and the percentage reduction in the mean flow is small for the engines with 40^0, 60^0, and 80^0 shrouded intake valve as compared with the same engines using poppet intake valve. However, in comparison to the same, the percentage increase in swirl ratio and the percentage reduction in mean flow for the engines with 100^0 and 120^0 shrouded intake valve is moderate and for the engines with 140^0, 160^0, and 180^0 shrouded intake valve, it is substantially high. From Figs. 5(a) and 5(b), it can also be seen that the percentage variation of swirl ratio and mean flow coefficient within the SI engines on varying the shroud angle of shrouded intake valve is not affected by test pressure drop.

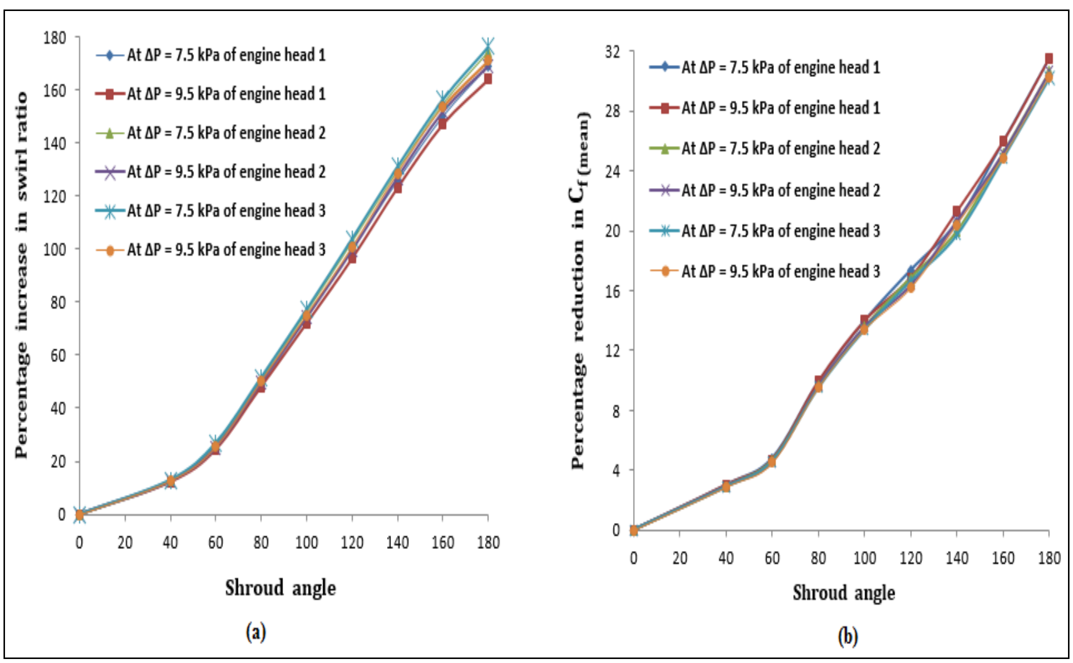

Figure 5: (a) %variation of swirl ratio (b) %variation of mean flow coefficient.

7. Data Correlation

A regression analysis is performed with the values reported in Figs. 5(a) and 5(b) to find correlation equations for prediction of swirl ratio and mean flow coefficient within an SI engine using shrouded intake valve of any degree of shroud angle. The obtained correlation equations are cubic equations since, a further increase in the polynomial degree of the correlation equations did not result in a rise in the value of R^2. Table 2 shows the value of R^2 and standard errors for the cubic correlation equations. Finally, the equations are validated by estimating the error between measured and calculated swirl ratio and mean flow coefficient for a number of engine heads using shrouded intake valve of different shroud angle at several test pressure drop. The error so estimated is found to be less than 1% in case of swirl ratio and less than 3.5% in case of mean flow coefficient as shown in table 3. Thus, swirl ratio and mean flow coefficient of an SI engine using shrouded intake valve of any shroud angle at a test pressure can be determined by simply finding the swirl ratio and the mean flow coefficient of the same engine with poppet intake valve and using the correlation equations.

For % variation of	Mean flow coefficient $C_{f\,(mean)}$	Swirl ratio (R_S)
Equations	Y = -1.98E-06x^3 + 1.07E-03x^2 + 4.08E-02x - 1.72E-01	Y = -3.85E-05x^3 + 1.34E-02x^2 - 2.07E-01x + 3.10E-01
R^2	0.995	0.998
Standard error of Y estimation	0.715	2.533

Table 2: Regression equations for prediction of % variation of R_S and $C_{f\,(mean)}$ w.r.t shroud angle

Engine head	Test pressure drop	Shroud angle	Measured R_S	Calculated R_S	% error	Measured C_f (mean)	Calculated C_f (mean)	% error
Head 1	8	170^0	3.521	3.610	2.528	0.223	0.220	1.345
Head 2	9	150^0	3.313	3.389	2.294	0.242	0.239	1.240
Head 3	7.5	70^0	1.944	1.905	2.006	0.294	0.290	1.695
Head 4	8	50^0	1.591	1.563	1.760	0.295	0.291	1.356
Head 5	9.5	120^0	2.920	2.864	1.918	0.252	0.248	1.587
Head 6	7	110^0	2.259	2.311	2.302	0.272	0.268	1.471

Table 3: Measured and calculated values and % error derived from measured value.

8. Conclusion

From the study, it can be concluded that the percentage increase in swirl ratio and the percentage reduction in the mean flow for the engines with 40^0, 60^0, and 80^0 shrouded intake valveis small as compared with the same engines using poppet intake valve. While, for the engines with 100^0 and 120^0 shrouded intake valve the percentage increase in swirl ratio and the percentage reduction in the mean flow is moderate and for the engines with 140^0, 160^0, and 180^0 shrouded intake valve, it is substantially high as compared with the. Further, it is seen that the proposed correlation equations can be used for prediction of swirl ratio and mean flow coefficient within an SI engine using shrouded intake valve of any degree of shroud angle.

Engine Head	Head 4	Head 5	Head 6
Bore x Stroke (mm)	83 x 90	68 x 54	94 x 86
Number of intake valve	2	1	2
Intake valve diameter (mm)	31	26	30
Seat angle (degree)	44.5	45	35
Inclination (degree)	10	0	65
Maximum lift of intake valve (mm)	8.0	6.5	7.0
Intake valve opening duration (degree)	244	232	246

Table 4: Main specification of the other engine heads used for validation.

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