Design of Test Rig for Swirl Measurement in I.C. Engine

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Abstract— This paper gives the overall view of the swirl measuring techniques and its importance in the efficient combustion. The measurement techniques comprise of types, industrial development and research analysis. In the field of industrial development paddle wheel anemometer technique is best suitable. Angular momentum transfer is created in this test rig which resembles the actual conditions of the working engine for same valve lift. A common technique for characterizing the swirl within the cylinder has been to use light paddle wheel pivoted on the cylinder centerline with low friction bearings. The rotation rate of the paddle wheel is used for measurement of air swirl since this rotation rate depends on the location of wheel and its design and the details of the swirling flow. This technique has been outdated by the impulse swirl meter. Swirl Assists the engine design team in port design development and optimization of port for new development projects for cleaner and efficient technologies.

Key words: Swirl, paddle wheel, Angular momentum transfer, port design development

I. Introduction

Knowledge of air flow in an inlet port and air motion within the cylinder of high speed IC engines is of primary importance as it influences fuel–air mixing, combustion, emission and hence fuel economy of the engine. Fuel–Air mixing in the cylinder depends on its motion. If the rotational motion is perpendicular to the cylinder axis, then it is called as tumbling flow and if flow is about the axis of cylinder then it is called as swirling flow. Swirl ratio is a dimensionless parameter and also main mechanism for very rapid spreading of flame front during the combustion process. Hence it is important to measure the swirl ratio and to find out characteristics of the swirl. For the optimized value of swirl with minimum losses in the flow it is mandatory to study the characteristics of inlet ports. Conventional methods employed for measuring swirl are namely AVL paddle wheel anemometer, Ricardo impulse swirl meter, hot wire anemometer, Laser Doppler anemometer. Among these methods, the first two methods are used for industrial development and other two for research analysis.

As we know the adverse effects due to emission like greenhouse effect, ozone layer depletion and global warming have unfavorable effects on the environment. Hence it a grave challenge in front of whole world to reduce the emissions. Considering the seriousness of the issue the developing countries like India have change their agenda by skipping the BS5 and implementing BS6 by 2020. So, it is very important to meet emission norms and to make cleaner and efficient technology. For this complete combustion of fuel is obligatory and hence swirl measurement is imperative.

II. Manuscripts

A. Concept:

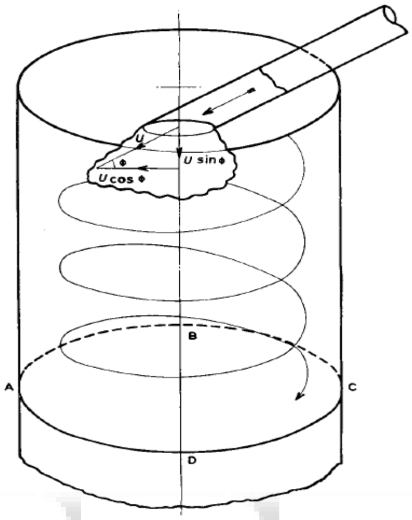

Fig. 1: Concept of swirl

Swirl usually is defined as the organized rotation of the charge about the cylinder axis. It also possesses momentum. We also know that in CI engines the efficiency depends on the quality of combustion and combustion depends on the eminence of the air fuel mixture generated in engine cylinder. The superiority of the air-fuel mix depends on the swirl generated in the engine cylinder. In actual engine swirl production vary continuously as the valve opening changes. To measure the swirl in this rig we simulate the condition of momentum transfer by the help of a blower. If two identical cylinder heads were fitted, one on the rig for steady state testing and other to an engine then for a given inflow and valve opening the produced angular momentum would be same in both the cases [1]. The readings are taken at a steady flow condition at different valve lifts. In order to co-relate the swirl flow test rig with actual engine following assumption are considered:

- Air flowing through intake ports in real engine and on steady flow rig is assumed to be compressible and isentropic.
- Swirl motion in the cylinder of both real engine and steady flow rig is rigid body vortex.
- Pressure drop as air flows through intake ports is constant during the intake process in the real engine i.e. air velocity passing through valve seat is constant during intake process. [4]

B. Various swirl measurement techniques:

Swirl of engines in working condition is directly measured only with the test engines equipped with optical access by using LDV (laser Doppler velocimetry) or PIV (Particle image velocimetry) techniques [2]. Other methods for measurement of swirl include “Water Analogue” test rig and the Imperial Collage pulse flow arrangement. But these methods of swirl measurement are costly and hence not feasible for testing. This led to the development of alternate techniques of swirl measurement such as stationary flow benches. Ricardo and AVL have carried out further research and development in the field of swirl measurement using steady flow benches for the precise measurement of swirl. Furthermore, methods such as numerical methods and swirl simulation techniques are also developed for measuring swirl. These methods provide an alternative for experimental techniques.

C. Description of setup:

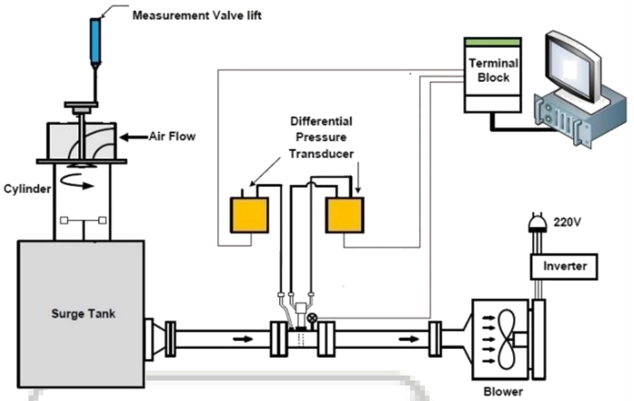

Fig. 2: Block diagram of setup

A common technique for characterizing the swirl within the cylinder has been to use light paddle wheel pivoted on the cylinder centerline with low friction bearings. The paddle wheel diameter is close to cylinder bore and its position is 1.5 of the bore diameter from the firing head [12]. Fitgeorge and Allison suggested that the paddle wheel is place at 0.8 to 1.4 times of the bore diameter from firing head to measure fully developed swirl value. Other authors suggested that fully developed flow is obtained at 1.75 of the bored dimeter from firing head. The rotation rate of the paddle wheel is used for measurement of air swirl since this rotation rate depends on the location of wheel and its design and the details of the swirling flow, this technique has been outdated by the impulse swirl meter. It measures the total torque exerted by the swirling flow [12].

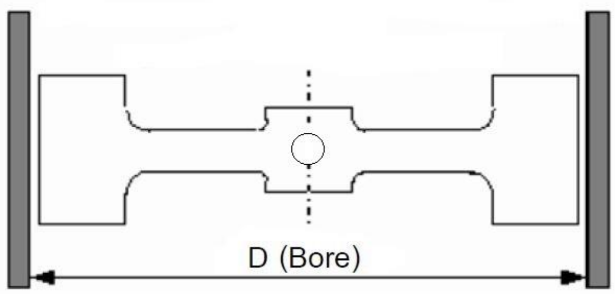

Fig. 3: Paddle Wheel

For simulating the engine flow in the test rig, suction is created with the help of blower and hence the momentum transfer condition is satisfied in the cylinder/liner at different valve lifts. The valve lifts can be adjusted by using a depth gauge. For the readings to be taken it is mandatory for the flow to be steady. To satisfy this condition surge tank and valves are used with blower. Vacuum is created in the surge tank. The surge tank is designed in such a way that it can withstand high compressive forces. Orifice plate is used to calculate mass flow rate in the setup. Which is mounted in the piping assembly at a distance where the flow becomes steady. To reduce the length the of the piping assembly flow straighteners or bunch of tubes are placed at the inlet of the pipe. Pressure gauges and RH meter is used to calculate suction pressure and relative humidity respectively which is used to find out the density of air. Parameters required for the measurement of swirl are calculated by paddle wheel installed in the cylinder.

D. Working of the setup:

Two differential pressure manometers that measure the intake air flow rate and surge tank pressure, a photo sensor that counts the paddle revolutions, a depth gauge that adjusts the valve lift, and manually operated bypass valve for adjusting surge tank pressure respectively in the traditional swirl-measurement equipment. For the measurement of the swirl ratio of the cylinder head, the Air is sucked by a blower through the port over a valve with an adjusted lift, past the cylinder liner and surge tank, and into the flow nozzle. A pulse pick-up transmits the paddle wheel rotation to an optical counter. The number of pulses for a given time interval are measured with counters, and the measurement provides the rotation speed of the paddle wheel. The pressure loss (ΔP) across the flow nozzle is measured with manometer. This procedure is repeated after adjusting the valve lift several times. The valve lift of the cylinder head is controlled by the depth gauge. After the valve lift is adjusted to a large position, the bypass valve is controlled manually to obtain the target surge tank pressure. Therefore, the valve movement time interval between consecutive valve lifts cannot be constant when measuring the swirl in a steady flow. When the valve lift was increased continuously with a constant time interval with the bypass valve closed, the intake flow in the cylinder is in quasi-steady state. The valve lift in the quasi-steady flow is adjusted continuously. The observations required from the swirl measurement equipment were measured and recorded in a data, while the valve lift was adjusted continuously with a constant time interval. The surge tank pressures, the differential pressure at the flow nozzle are measured at each valve lift. The paddle rotating speed was calculated from cumulating the count of the photo sensor signals during a time interval of the adjustment between consecutive valve lifts.

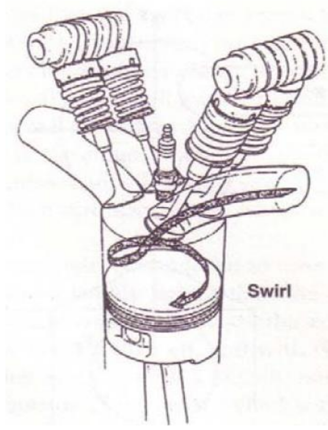

Fig. 4: Swirl in engine

E. Swirl test rig capabilities:

- All Determination of Mean Swirl and Mean Flow Coefficients for intake ports
- Paddle Wheel and Impulse Swirl method tests.
- Dedicated Swirl test rig with advanced data acquisition systems.
- Manufacturing of Ports and Flow boxes.

Assisting Engine Design Team in Port Design Development and optimization of port for new development projects.

F. Parameters:

1) Swirl ratio:

It is a ratio of rotation of paddle wheel placed inside the engine cylinder to the equivalent engine speed.

$$Rs=Nd/N$$

Where,

Nd - speed of paddle (RPM)

N - Equivalent engine speed (RPM)

2) Equivalent engine speed:

$$N=30*m/(\rho*Ac*S)$$

Where,

m – mass flow rate (Kg/s)

ρ – density of air (Kg/m^3)

Ac – sectional area of cylinder (m^2)

S – stroke length (m)

3) Mass flow rate:

$$m = Cd * A * \sqrt{(2 * \rho * (P1-P2))}$$

where,

m = mass flow rate (kg/s)

Cd = coefficient of discharge for orifice

A = area of flow orifice (m2)

ρ = density of air (kg/m3)

ΔP = pressure difference (N/m2)

4) Axial flow velocity:

$$Va = m/ (\rho * A_c)$$

5) Mean piston speed:

$$Vm = (S * N)/30$$

Where,

N – engine speed (RPM)

6) Helix angle(Φ):

It is the angle made by inlet port with the horizontal plane.

$$\Phi = Cot^{-1}(Vu/Va)$$

7) Flow Coefficient (Cf):

The flow coefficient of the intake port in the engine cylinder head is the parameter used to evaluate the degree of flow restriction through the intake port.

$$Cf = (m*s)/(\rho*Ao*Vo)$$

Where,

Vo – Velocity of air at inlet port

Ao – Area of inlet port

8) Mean flow coefficient:

$$Cf(mean) = (\int_{\alpha 2}^{\alpha 1} Cf\ d\alpha)/(\alpha 1 - \alpha 2)$$

Where,

α1, α2 – Angles corresponding to lift from lift-crank angle diagram

Apart from the above parameters valve lift, pressure drop, differential pressure across orifice, circumferential velocity, paddle wheel diameter, cylinder bore, density of air at intake condition (Po & To).

By taking readings from setup following graphs are drawn for analyzing the results. These results can also be plotted using software's like MATLAB.

1) Discharge Vs Lift/Diameter ratio
2) Mass flow Rate Vs Lift/Diameter ratio
3) Paddle wheel rpm Vs Lift/Diameter ratio
4) Circumferential velocity Vs Lift/Diameter ratio
5) Axial flow velocity Vs Lift/Diameter ratio
6) Helix angle vs Lift/Diameter ratio
7) AVL Swirl Rating Vs Lift/Diameter ratio
8) Flow Coefficient Vs Lift/Diameter ratio

Where Efficiency and emissions are not a concern then low values of swirl are desirable e.g. Racing engines. When efficiency and emissions are of primary importance then higher values of swirl are desirable.

III. Future Scope

For lowering the emissions, complete combustion of fuels is mandatory hence swirl measurement is important. Value of Swirl is used in the designing of cylinder head and further the testing of these cylinder heads can be carried out by casting the designs using epoxy resins and polymers. Paddle wheel Anemometer has been observed to have less sensitivity towards measuring swirl at lower valve lifts so it is necessary to make more accurate setups. Results can also be plotted using software's like MATLAB.

IV. Conclusions

A thorough study has been done regarding the designing, operation and parameters of the swirl test rig. AVL and Ricardo swirl measuring techniques are widely used in industries for design and development of cylinder heads. It has been observed that steady state flow condition must be fulfilled for measurements to be taken. In such test rigs, it is difficult to fulfil the actual condition of real time working engine.

The value of swirl is an important parameter in the design and development of inlet, exhaust ports and the cylinder heads.

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References

[1] D. Fitzgeorge, J. L. Allison, "Air Swirl in A Road-Vehicle Diesel Engine", Proc Instn Mech Engrs (A.D) No.4 1962-63

[2] Forte Claudioa, Catellani Cristiana, Cazzoli Giulioa,, Bianchi Gian Marcoa, Falfari Stefaniaa, Brusiani Federicoa, Verzè Alessandrob, Saracino Stefanob, "Numerical evaluation of the applicability of steady test bench swirl ratios to diesel engine dynamic conditions energy procedia" 81 (2015)732 – 741.

[3] Rajinder Kumar Soni, Pranat Pal Dubey, "Diesel engine air swirl mesurements using avl test rig", issn 0976 – 6340 (print) issn 0976 – 6359 (online) volume 4, issue 1, january- february (2013), pp. 79-91.

[4] A Shankar. V, Thejaraju R, Varunraju V, Amal Chacko K," Experimental Studies on The Intake Port of a Diesel Engine to Determine Swirl", International Journal of Recent advances in Mechanical Engineering (IJMECH) Vol.5, No.2, May 2016
[5] G.S. Gosavi, R.B. Solankar, A.R. Kori, R.B. Chavan, S.P. Shinde "swirl measuring equipment for direct injection diesel engine", ijarse, vol. no.4, special issue (01), march 2015
[6] C. Ramesh Kumar, G. Nagrajan," Ivestigation of Flow during Intake Stroke of a Single Cylinder Internal Combustion Engine" ARPN Journal of Engineering and Applied Sciences Vol.7, No.2 2012
[7] Bidesh Roy, R.D.Mishra, K.M.Pandey, "Swirl Ratio and mean Flow Coefficient Within S.I Engine Using Shrouded Intake Valve and Correlation Relations for its Prediction",ijird Volume4 issue 13 (2015)
[8] C.Crnojevic, F.Decool, P.Florent, "Swirl Measurement in Motor Cylinder", Experiments in fluids 26 (1999)
[9] John L. Lumley," Flow in the Cylinder", Cambridge university 1999
[10] Daesan Oh, Choong Hoon Lee "Flow coefficient measurements for an engine cylinder head under transient flow conditions with continuous valve lift change" daesan oh et al. / international journal of engineering and technology (ijet) (2015)
[11] E. Pipitone, U. Mancuso, "an experimental investigation of two different methods for swirl induction in a multivalve engine" University of Palermo, Italy. (2004)
[12] "Fluid Mechanics" by Cengel
[13] "Internal Combustion Engine Fundamentals"by John B. Heywood