ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 2, Issue 1, pp: (167-172), Month: April 2015 – September 2015, Available at: www.paperpublications.org

Study of Tumble Measurement on a Steady State Flow Rig

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Abstract: **This paper deals with the study of Tumble flow on a Steady State Flow Rig. Recently stratified charge lean burn engines and gasoline direct injection engines (GDI) are being developed in order to reduce CO_2 emission. In these combustion concept, tumble or inclined axis swirl is required not only to enhance turbulence intensity before combustion but, also to control mixture stratification and air-fuel concentration distribution. Tumble flow is the flow of charge along a line perpendicular to the vertical axis of the cylinder. Its mainly depend upon inlet port design, piston head design shrouding of valve and orientation of inlet port. There are various methods used to calculate the tumble flow, which are PIV (Particle Image Velocimetry), PTV (Particle Tracking Velocimetry), LDA (Laser Doppler Anemometry) and Steady State Flow Rig. Here we are concentrating on the Steady State Flow Rig with a paddle wheel arrangement. This test rig helps in designing suitable intake ports. This test rig measures the tumble in terms of paddle wheel RPM in accordance with the valve lift. Working principle of this test rig and its limitations are studied.**

Keywords: **Tumble, Steady State Flow Rig, Valve Lift.**

1. INTRODUCTION

Strict emission regulations and high gas price have demanded the development of new technologies to achieve higher thermal efficiencies and zero exhaust emissions. The call for environmentally compatible and economical vehicles, still satisfying demands for high performance, necessitates immense efforts to develop innovative engine concepts.

Among the many design goals of combustion engines, the mixing process of fuel and air occupies an important place. If a good mixture can be achieved, the resulting combustion is both clean and efficient, with all the fuel burned and minimal exhaust remaining. In turn, the mixing process strongly depends on the inflow of the fuel and air components into the combustion chamber or cylinder. If the inlet flow generates sufficient kinetic energy during the valve cycle, the resulting turbulence distributes fuel and air optimally in the combustion chamber.

Thus it is clear that the air motion within the cylinder of internal combustion engines has a fundamental effect on combustion and hence on engine performance and exhaust emissions. In-cylinder flow control is one of the most effective tools for affecting combustion qualities in the internal combustion engine. The flow in the cylinder is broadly classified as follows-

1. Swirl

2. Tumble

These two parameters represent the fluid flow behaviour occurred inside the combustion chamber. Flame development, propagation, extinction, air/fuel mixing including stratification, and so on are partially or dominantly affected by the swirl and tumble flow. They are used to maintain the flow's kinetic energy until the late stage of the compression stroke, when it dissipates or breaks up into micro-scale turbulence to promote the early flame kernel growth and to speed up the flame propagation.

2. IMPORTANCE OF TUMBLE MOTION IN S.I. ENGINE

Nowadays the modern lean-burn stratified and direct injection spark ignition internal combustion engines are becoming more popular because of their low fuel consumption and exhaust emissions. In the efforts to reduce the emissions of internal combustion engines, the lean-burn strategy has been proved effective. Tumble flow is now popularly employed in multi-valve automobile S.I. engines for improving combustion and engine performance. In recent years it is even more used for organizing the stratified charge lean combustion system or gasoline direct injection (GDI) combustion system.

However, the burning speed of a lean fuel-air mixture is slower, which reduces the engine performance and constrains the improvement in engine emissions. The drawbacks of lean-burn engines in the slow combustion speed and the low engine performance may be improved by providing adequate in-cylinder flow motions. As the turbulence intensity of the in-cylinder flow increases, the flammable range of the premixed combustible gases broadens. Accordingly, the fuel-air mixture becomes easier to be ignited such that the flame propagation speed is increased and the cyclic variability is significantly reduced. Shortening in the combustion duration will make the engine to possess the potential to be operated at higher speeds and to develop higher engine outputs.

This can be achieved by enhancing the tumble motion within the engine cylinder which enhances the mean flow and turbulence of the mixture. Increased tumble strength produces an increase in the turbulence intensity late in the compression stroke, and in the mean flow velocity near the spark plug at the time of spark discharge, thus achieving convection of the flame away from the spark plug during flame development and faster flame propagation during the main combustion period which controls combustion efficiency and formation of pollutants through large and small-scale mass and heat transfer.

3. DEVELOPMENT PROCESS OF TUMBLE IN THE CYLINDER

During the induction process of an actual engine, the conditions met by tumble and swirl are completely different from the conditions in a steady state flow-bench. For example, at the early stage of induction, tumbling flow entering into the cylinder is severely influenced by the piston position, since, the top surface of the piston can be so close to the cylinder head that the tumbling flow impinges immediately on the top surface of the piston and changes randomly its moving direction. A swirl motion, however, can continue its movement along the cylinder wall at that time. That is to say, on a tumble steady state flow-bench, although a plate is provided at the bottom end of the dummy liner to simulate the piston, it is too far away from the cylinder head to represent the piston condition closing to TDC. Therefore, the physical process tumble flow suffers from in an actual engine cylinder are as follows:

1. Early stage of induction: The tumbling flow direction is destroyed by the top surface of piston and so the obtained tumbling angular momentum at this stage is zero, even though an angular momentum or tumbling speed can be measured at the relevant valve lift on the steady state flow-bench.

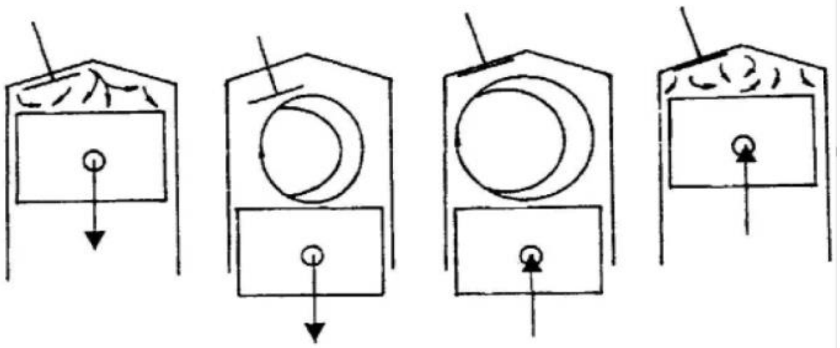

Figure 1: Physical Process of the In-cylinder Tumble

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2. Middle and late stages of induction: When the top of piston is far enough from the cylinder head or after a certain crank angle, tumble starts its formation process and the angular momentum can be integrated thereafter.

3. Early and middle stages of compression: Tumble in the cylinder is retained and developed.

4. Late stage of compression: The upward moving piston compresses Tumbling motion in the cylinder. Because the shape and the narrow space of the combustion chamber are not suitable for the way of the tumble flow, it distorts and breaks up gradually into turbulence and the intensity of turbulence increases obviously.

As mentioned above, it seems that, there exists a critical crank angle ϕ. When crank angle $\theta \leq \phi$ after TDC during induction process, tumble cannot be formed effectively in the cylinder; while when $\theta \leq \phi$ during compression process before TDC, tumble distorts and breaks up into turbulence. [2]

4. STEADY STATE FLOW RIG

A steady flow rig is widely used to measure the flow coefficient, swirl ratio, and tumble ratio of a cylinder head. Tumble ratio in the steady rig is usually measured using an impulse torque meter or a paddle wheel. For the steady rig tumble measurement L or T-type adaptor between a cylinder head and an impulse torque meter or paddle wheel needs to be installed. Tumble ratio measurement using a steady flow rig is the cheapest, easiest, and fastest method among other tumble measurement methods even though it also has following shortcomings-

1. Since a steady rig measures the tumble or swirl ratio at a fixed valve lift without operating the valve and calculates a tumble or swirl ratio based on the valve profile, the measured tumble ratio would be different from that of a real engine. Thus, in-cylinder flow variations due to valve timing changes in a VVT engine cannot be anticipated from the steady rig measurements.

2. While in-cylinder flow has a 3- dimensional flow structure, steady flow rig test is not able to reflect the 3-Dimensional flow characteristics of an in-cylinder flow.

3. Steady flow rig calculates a tumble or swirl ratio based on the assumption of a rigid body rotation of the in-cylinder flow. However, real in cylinder, flow is much different from that of a rigid body bulk flow assumption.

In spite of these limitations the steady rig method for tumble flow measurement is still widely used because of its convenience, low cost, and quickness.[4]

A blower is used in order to create flow. The blower is used in two modes:

1. Suction mode- It is used to study intake parts e.g. intake manifold and intake port. In this mode, air is sucked from ambient to simulate actual state in engine

2. Blowing mode which is used to study outlet parts e.g. exhaust manifold and exhaust ports. In this mode, air is blown to ambient to simulate actual state in engine.

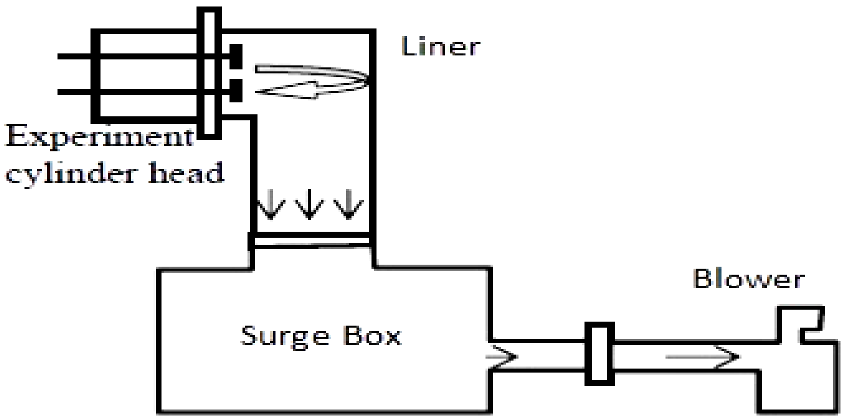

Figure 2: Steady State Flow Rig

ISSN 2393-8471

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5. PARAMETERS USED IN TUMBLE MEASUREMENT

The steady flow testing of cylinder heads is a widely adopted procedure in the development of engines and it is used to assist and assess the design of the engine ports and the combustion chamber concerning the engine flow capacity and the in-cylinder flow pattern of the charge motion, which are critical to the engine combustion performance. The parameters used are as follows.

1. Discharge or Flow coefficient.

2. Tumble ratio.

A. Discharge and Flow Coefficient:

It is the ratio of the measured mass flow rate to the theoretically calculated flow rate through a reference flow area in the port/valve assembly. This flow rate ratio is commonly called 'discharge coefficient' or 'flow coefficient', depending on which flow area is used as the reference.

Discharge Coefficient:

$$C_d = \frac{m}{\rho\, A_v V_0}$$

$$V_0 = \sqrt{\frac{2\Delta p}{\rho}}$$

The discharge coefficient (C_d) decreases with valve lift, reflects the flow restriction produced by the valve and seat lips at low valve lifts which then determine the flow orifice area.

Flow Coefficient:

$$C_f = \frac{m}{\rho A_p V_0}$$

$$V_0 = \sqrt{\frac{2\Delta p}{\rho}}$$

The flow coefficient (C_f) increases with valve lift, reflects the restriction by the port geometry, when the gap area between the valve and seat lips becomes comparable to or beyond the port throat area.[6]

B. Tumble Ratio:

The prediction of the in-cylinder tumble speed or tumble ratio is based on the following assumptions:

1) Angular momentum of the tumbling flow into the cylinder during the induction process is conserved.

2) Skin friction does not impede the tumble motion.

3) The characteristics of the inlet port, e.g. the flow coefficient and the ability of tumbling motion, retain the same as they do under the steady flow rig condition.

The tumbling flow is usually characterized by the moment of angular momentum about a chosen axis. The angular momentum flux in the engine cylinder, G, is a function of crank angle during the induction process. In the steady flow test, it is a function of valve lift for a given flow rate or pressure drop. The linear ratio of this angular momentum flux to the fictitious engine speed corresponding to the test condition is called the 'Tumble ratio'.[6]

$$T.R = \frac{\text{angular momentum flux}}{\text{engine speed}}$$

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$$T.R = \frac{2S}{\rho Q^2} G$$

6. EXPERIMENTAL SETUP

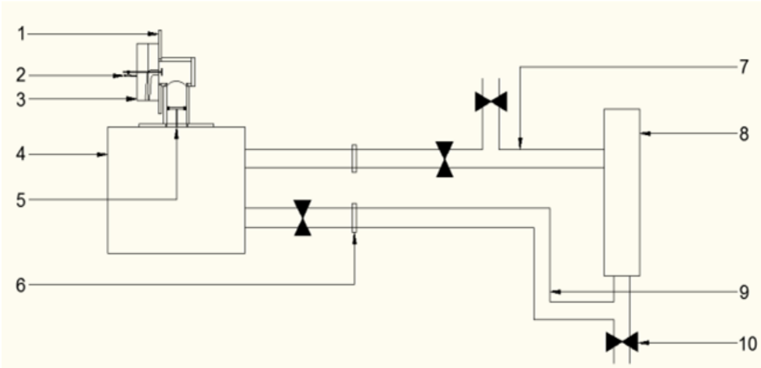

Figure 3: Tumble Measurement Setup

Table 1: Components of Test Set-up

No.	Part Name	No.	Part Name
1	Liner	6	Orifice Meter
2	Micrometer arrangement	7	Inlet Pipe
3	Cylinder Head	8.	Blower
4	Surge Tank	9.	Outlet Pipe
5	Paddle Wheel	10.	Control Valve

The test rig consist of a vacuum tank which holds a paddle wheel on the top, the paddle wheel is connected to the DAS which displays the speed of paddle. A paddle wheel is pivoted on cylinder centre line with low friction bearings mounted at 1.75 times the bore diameter down to the cylinder. The paddle wheel diameter is 0.917 times the cylinder bore. The motor is connected to a blower a variable ac controller of 25 hp capacity controls the speed of the motor, speed of the blower is controlled to maintain constant tank pressure. The dummy liners on which the ports are fitted are of various diameters and are selected according to the bore diameter; the valve lift can be increased or decreased with the help of the depth micrometer fitted on cylinder head.

During intake port testing the air is sucked into the vacuum tank, the blower speed is controlled so that pressure inside the vacuum tank is maintained constant. For higher valve lifts a pressure of 250 (mm of water) is maintained. As the valve lift (up to 5 mm) value decreases a higher pressure of order 600 (mm of water) in the maintained for further valve lifts. For exhaust port testing, a constant level of 500 (mm of water) is maintained.

7. EXPERIMENTATION

1. First the liner assembly would be mounted on top of the surge tank of the setup. Then the cylinder head of GDI engine mounted on liner assembly whose bore equal to bore of the liner.
2. The control valves of the setup would be adjusted for the inlet testing of the head.
3. The valve lift would be change gradually for different readings with the help of depth micro meter. Pressure drop across the tank is maintained by varying the speed of blower.
4. The pressure drop before the orifice plate, pressure drops across the orifice and paddle wheel speed is obtained from DAS (Data acquisition System) through sensors.
5. The procedure in above step is repeated for the subsequent readings of valve lifts.
6. By putting the obtained data in the formulae described in above sections the tumble value would be calculated

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8. NOMENCLETURE

Table 2: Nomenclature of the Design Elements

Symbol	Quantity
T.R	Tumble Ratio
C_d	Coefficient of Discharge
M	Mass Flow-rate
P	Density
A_v	Cross-Section Area
Δp	Pressure Difference
C_f	Tangential force,
G	Momentum Flux

9. SUMMERY

1. From the above study it can conclude that the tumble ratio in the MPFI and GDI engines can be found out on the steady state flow rig which used for swirl measurement by using a liner assembly.

2. The same test rig can be used to find swirl ratio as well as tumble ratio for the various bore diameters.

ACKNOWLEDGEMENT

We are thankful to our Project Guide & Coordinator Prof. R. V. Patil Sir and faculty of Department of Mechanical Engineering, Sinhgad Institute of Technology & Science, Narhe, Pune for giving this opportunity to enhance our project study.

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