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The Effect of Inlet Port Geometry on In-Cylinder Flow Structure

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ABSTRACT

The effect of intake port shape of two-valves heads of V-8 D.I. diesel engine with stroke I20 mm and diameter I20 mm on the in-cylinder bulk flow and turbulence structure was investigated by using laser doppler anemometry(LDA) in steady flow tests. The results, obtained at constant mass flow-rate in a plane I20 mm one bore from the cylinder head, confirmed the expected differences both in swirl and axial directions characterized by generation of reversed flows. The swirl center of main vortex was found off-axis with a counter-rotating secondary vortex near the cylinder axis. As far as the axial velocity components are compared, the major features are of marked non-uniformity with a reversed flow close to the axis. Integrating of the product of the measured tangential and axial velicity components allowed the momentum flux related to the cylinder axis. The calculated values were used for comparison with results obtained by using vane anemometer and tourque meter.

INTRODUCTION

Flow phenomena inside the liner of an internal combustion engine have become on the major design parameters in modern engine developments. The in-cylinder air motion prior to injection in D.I. diesel engines is of primary importance since its interaction with fuel sprays determines the efficiency of air-fuel mixing and combustion processes. One way of enhancing air-fuel mixing is to select rational vortex intensity and to increase the turbulent level by providing suitable swirl inducing ports for intake.

Traditionally the swirl-generating characteristics of inlet ports have been determined using tourque meter or paddle wheel anemometer under steady state flow conditions (I, 2). Such measurements can be used usually to derive a "swirl number (SN) or "swirl ratio" (SR) for rapid comparison of characteristics of different port designs, but they yield no detailed structural information about the swirl movement. It would appear from studies of recent years that the swirl structure is of great importance on the value of angular momentum flux (3). Recent experimental studies in the liners of real and model engines as well as in steady flow rigs underlined the complexity of such vortex flows.

The purpose of this study is to analyze the aerodynamic field downstream of the inlet port of an industrial diesel engine produced by KamAZ having stroke I20 mm and diameter I20 mm. An investigation of the in-cylinder engine flows resulting from the intake process was taken at an axial distance of I20 mm (D) from the cylinder head, using laser doppler anemometry (LDA) . As used here, they have the advantage that the cylinder liner can be constructed with a high degree of optical access for detailed LDA measurements and two - dimensional flow mapping of the velocity and turbulence components. Three cylinder heads with tangential inlet ports of various shape were mounted in a steady flow rig to compare the aerodynamic field and turbulence structure under steady flow conditions. A sketch of cylinder head with experimental inlet ports is shown in Figure I.

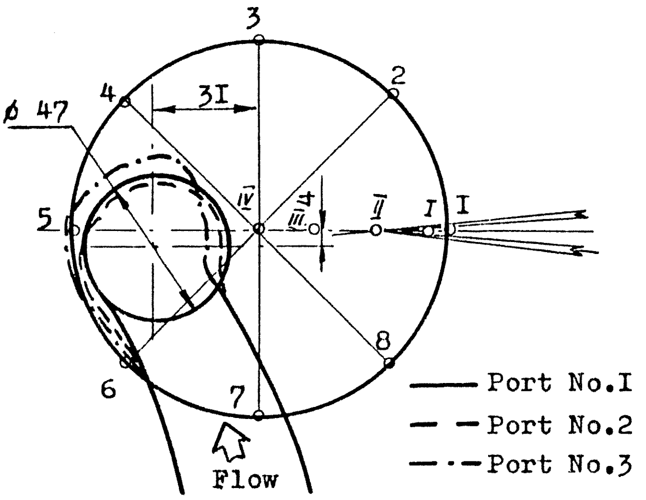

Fig. I Inlet ports, measurement axis and points for the steady flow rig

The validity of such approach was discussed in (5) . In a preliminary step the comparative flow and swirl characteristics of experimental inlet ports were investigated. Measurements of flow coefficient uo and swirl coefficient n_D/n were obtained at the fixed pressure drop across the port-valve assembly 250 mm water gauge, using paddle wheel anemometer KS-3708 of AVL and AVL's evaluation procedure (2) . Also were taken measurements of swirl parameters using tourque meter at pressure drop of 800 mm water in a plane 80 mm from cylinder head in connection with accepted in NTC PO "KamAZ" evaluation procedure. The results of preliminary tests are shown in Figure 2 and summerized in Table I also.

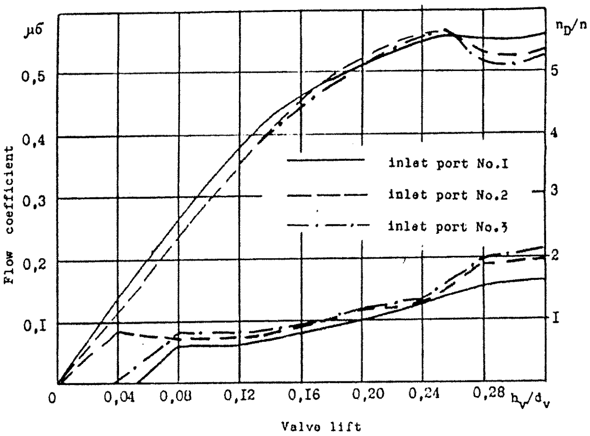

Fig. 2 Flow and swirl parameters of inlet ports

Table 1 Comparative characteristics of experimental inlet ports

Head No.	M_s, kG·sm	$(n_D/n)_m$	$(\overline{\mu\sigma})_m$	M_Σ, Nm
1	2,6	1,500	0,386	0,093
2	3,2	1,725	0,381	0,173
3	3,8	1,755	0,376	0,140

EXPERIMENTAL APPARATUS AND PROCEDURE

A sketch of the experimental set-up is shown in Figure 3. The cylinder heads were mounted onto a rotating liner with diameter I20 mm. The experiments were performed using fixed (middle) valve lift 6 mm and a constant flow rate of 96,5 l/s, which corresponds to the mean rate of air displacement equal to the mean piston velocity at an engine speed of 2200 rpm (5). The air flow is controlled by a series of pressure and flow regulators, monitored

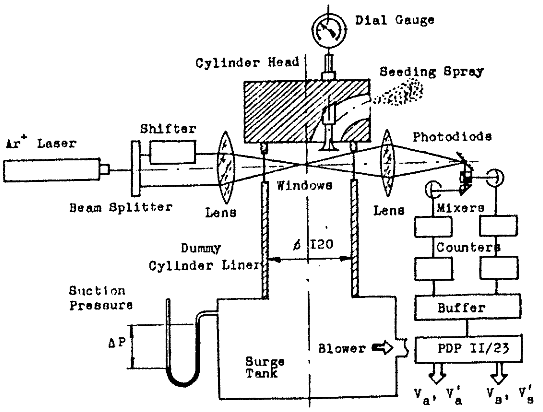

Fig. 3 Experimental apparatus

by a standard orifice meter and exhausted through a plenum connected with the liner.

LDA assembly consisted of a two-component three-beam optical system (DANTEC mod. 55X) using an argon-ion laser (Spectra Physics mod. 2020) , Bragg cell frequency shifters, beam expander, backscatter and forwardscatter modules (6) . A counter type signal processor (DANTEC mod. 55L90a) gave a discrete sample of the velocity each time a particle have crossed the beam intersection point, coupled with PDP II/23 minicomputer. The LDA system parameters are listed in Table 2. The axial and tangential components of the gas velocity were measured at four locations along eight radial orientations , spaced 45 degree apart. The measurements of the radial velocity components were more dificult and performed only in special cases. Ensemble averaging over 500 samples was used at each location to lower the statistical uncertainty. For measuring of velocity components the liner was equipped with two opposite dispaced 20 mm useful diameter quartz windows, located at the distance of I20 mm (D) from the cylinder head. A micron seized TiO_2-ethanol mixture, pulverised in a close proximity to the inlet port, was used for seeding the flow.

Table 2 LDA system parameters

Laser type	5W Argon-Ion
wave length	488,0; 514,5 nm
LDA optics	3-beam,2-colour
focal length	600 mm
beam separation	50 mm
beam angle	4,770°
probe volume diameter	0,38; 0,40 mm
probe volume length	2,00; 2,10 mm
fringe spacing	5,86; 6,18 um
frequency shift	3 - 5 MHz

All statistical information of the measurements is contained in the probability-density distribution, shown in Figure 4. To reconstruct the flow pattern v_s and v_a were used as a measure of the mean velocity and their standard deviations - as a measure for the turbulent fluctuations v_s' and v_a'. Besides the information about mean velocity and turbulence, also the shape of distribution ("skewness") was taken into account.

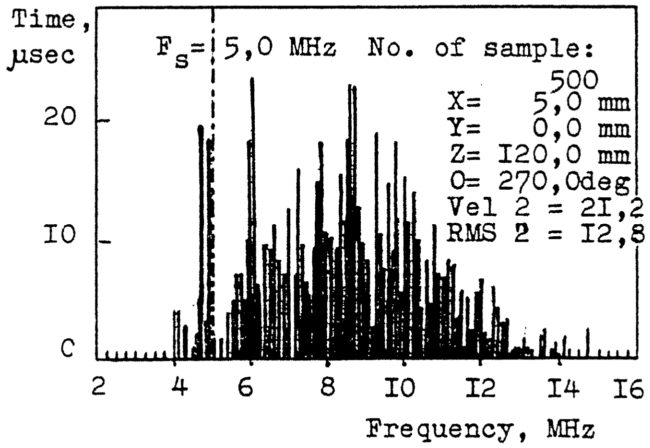

Fig. 4 Histogram of probability-density velocity distribution

RESULTS AND DISCUSSION

Figure 5 shows the tangential (a) and axial (b) mean velocity profiles as well as appropriate rms velocity components along eight radial orientations at

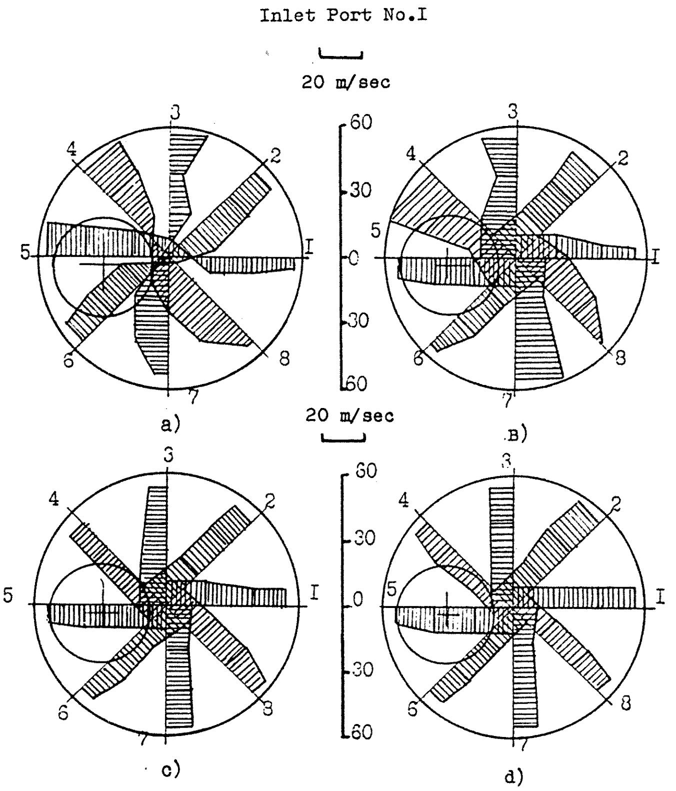

Fig. 5 Tangential (a), axial(b) mean and accordingly rms (c),(d) velocity profiles for inlet port No.I

the distance: 5.0; 23.3; 41.7 and 60 mm from the liner wall, generated by the inlet port of head No.I (M_s = 2.6 kG·sm) . The swirling structure of the air motion is clearly evidenced. More detailed analysis of swirl air motion shows that flow picture is agreed with solid body rotation only at radii 5 and 6. At the other radii it is observed more or less notable deviation from the mentioned law. It expresses in either nonlinear change of velocity profiles along some radii or in step-by-step increasing of tangential velocity components when approaching to the cylinder centerline. In tangential plane the main vortex seems to have been forced towards the inlet valve, its rotation axis doesn't coincide with the cylinder one being indicative of flow complexity in the vicinity of axial zone.

A notable non-uniform flow is observed also for axial velocity components. In most cross-section it is marked well-defined splashes of axial components either in central region or in cylinder periphery besides radii No.5 and No.2 where relative uniformity takes place. Despite the presence of notable velocity gradients turbulence fluctuations along each radius are fairly uniform and may be considered as isotropic. At some points the intensity of turbulence, defined as ratio of rms to proper value of mean velocity component due to large gradients however may exceed 100%.

Swirl movement, formed by the inlet port of head No.2, as it is seen from Figure 6-a and 6-b in comparison with proper characteristics of head No.I inlet port, yields more ordered flow structure. Herein the zone of reversed patterns and rotation axis biasing are less expressed at the pictures of tangential velocity components. Axial components have some asymmetry along cylinder radii, but have

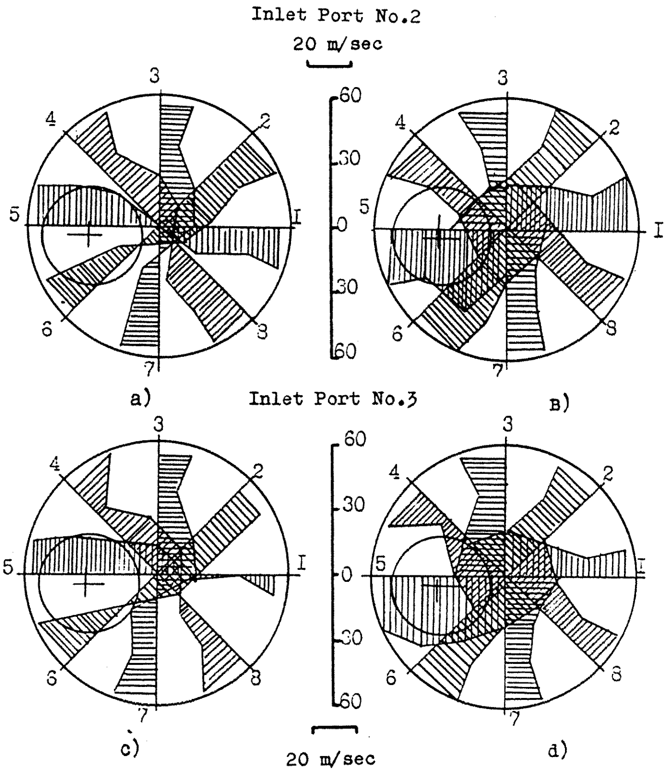

Fig. 6 Tangential (a,c) and axial (b,d) mean velocity profiles for inlet ports No.2 and No.3

neither uprising nor reversed patterns. On the whole the inlet port of head No.2 generates higher level of tangential and axial velocity components along all eight chosen radii, and relatively more noticeable turbulence intensity as against the other ports.

As for features of inlet port of head No.3 unlike the characteristics of head No.2 it forms fairly non-uniform flow along almost all radii and solid body rotation is valid merely for radii No.6 and No.8. As in the case of heads No.I and No.2, rotation axis doesn't coincide with the cylinder axis and instantaneous rotation axis accomplishes precession movement. The levels of absolute values of tangential velocity profiles at the periphery of cylinder as a whole(apart from radius No.I) are not lower when using head No.2, but with allowance of splashes in velocity radial distributions ordered swirl motion of air seems to be worse.

Obtained results were used for evaluation of integral momentum flux related to the cylinder axis in accordance with equation (7):

$$M_{\Sigma} = \rho \int_{0}^{2\pi} \int_{0}^{R} v_s \cdot v_a \cdot r^2 dr \cdot d\theta \ ,$$

where: ρ - air density; R - cylinder radius; v_s - swirl velocity component; v_a- axial velocity component.

The results of such accessment are presented in Table 2. They evidence that intensity of momentum flux related to the cylinder center, generated by the test inlet ports are arranged in the next lowering order: No.2; No.3; No.I. One have to keep in mind that flow tests with LDA were carried out at valve lift of 6 mm, that is at a point where $h_v/d_v = 0,I27$. The values of n_D/n in that point of valve lift range in accordance with data of Figure 2 are arranged in the next lowering order: No.3; No.2; No.I - in exact complience with the sequence being obtained on the test rig with the torque meter. The last data also listed in Table 2.

The assessment of momentum flux with LDA data may be pressumed to be more accurate due to more detailed investigation of flow structures and measurement of velocity components. To perform an adequate comparison of obtained values n_D/n with LDA data in real range of valve lifts it takes to investigate flow structure for every discretized valve lift h_v/d_v. Further in accordance with AVL evaluation procedure for $(n_D/n)_m$ estimation it is necessaryto summarize measured momentum fluxes M_i for every value h_v/d_v in the range of I5 - I65° of crank angle, taken with its weight coefficients.

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