The Experimental and Computational Investigation of the Flow in the Diesel Swirl Chamber

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ABSTRACT

In this paper, the air flow field in the swirl chamber of a motored diesel engine was measured by a Laser Doppler Anemometry (LDA). The tested diesel engine was S195 diesel engine with a bell type swirl chamber. This study concentrated on the flow fields during the compression stroke. Measurments were made at engine speed of 900r / min. The experiments data was acquired and processed by a quick data acquisition and processing system. Based on the measurments and modified k-ε turbulence model, a flow numerical model for the bell type swirl chamber of the tested engine was established. To compare the measured data with the calculated results showed that they were well agreed each other.

INTRODUCTION

The air-motion in the swirl chamber of a diesel engine is one of key factors to control air-oil mixing. Although the study on it has been carried out for several years, the measurment porcceding was limited to mechanical methods and water-simulation [1] [2] without correspondent calculated results. In recent years, new methods and computer technology have been empolyed in studies, but the measurement were conducted in fixed volume model and the results did not denote the real flow. In this paper, the air flow field in the bell type swirl chamber of the S195 diesel engine was measured by LDA. Based on the measurement results and modified K-ε turbulence model, a numerical model was tested and verified.

EXPERIMENTAL APPARATUS AND METHODS

The test engine is a reformed model S195 single cylinder bell type swirl chamber diesel engine, with bore 95mm, stroke 100mm, displacement 815cm^3, swirl chamber volume 25.7cm^2 and compression ratio 19. Two quartz windows are installed on each side of the bell type swirl chamber as the laser beam accesses unchanging volume ratio and compression ratio of the original engine (Fig.1). The measured area is about 80.2 percent of the section of the swirl chamber. the engine is motored via gear box.

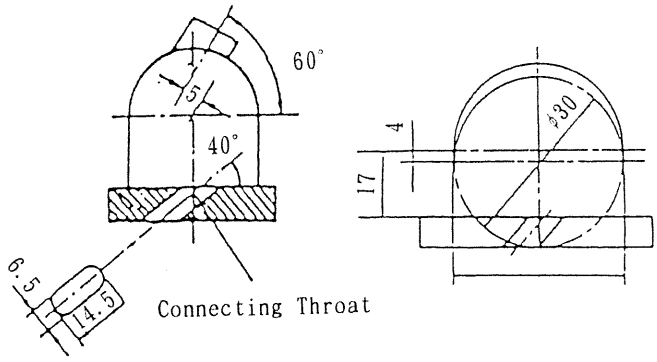

Fig.1 The size of swirl chamber and the measured area

The experimental arrangement consisting of three parts: (1) mechanic system driving the test engine (2) LDA (3) data acquisition and procession system are shown in Fig.2

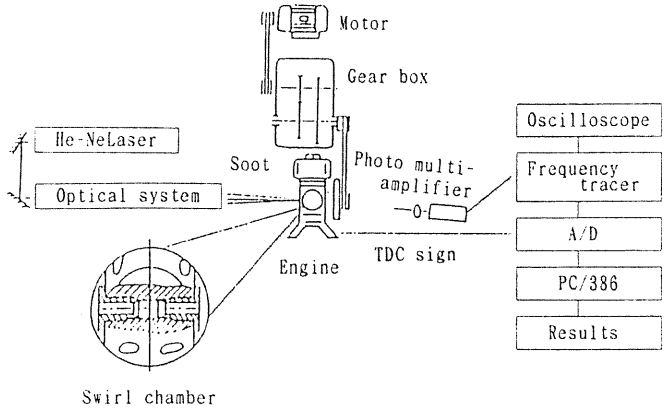

Fig.2 The experimental arrangement

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The LDA is a two demensional differential system. A laser beam is passed through a diffraction fringe rotated in a stable speed and diffracted to 0, ± 1, ± 2··· ··· order diffraction beams. The ± 1 order beams go through polalizers seperetely and become linear polalized laser beams. Then the 0 and ± 1 order diffraction beams are focused in the measurment point and interfer each other to form two groups of interference fringes vertical each other with preset frequency shift. This system could measure the two velocity components and judge the flow direction. When a particle suspended in air passes the fringes, it reflects laser lights with Doppler frequencies F_d. Then F_d is measured and the velocity component V_f in vertical direction of the fringes could cal culated by the formula:

$$V_f = \frac{\lambda F_d}{2\sin(\alpha/2)}$$

where λ is laser light wave length; α is laser beam intersection angle.

The LDA system consists of a 25mw He-Ne laser emmiting light with wavelength of 632.8nm, a F500mm launching len and a F300mm receiving Fourier len. The intersection angle of two beams is 3 ° . A kind of soot is sprayed into the swirl chamber via air intake as sizing particles. This dued to considering the relation between soot diameter and signal quality. The soot particle size is about 1.2μm and its density into the swirl chamber could be adjusted. The velocity of soot could approximately represents air velocity and could be actually calculated by computer:

$$V_f = 1.342 * 10^{-3} * (127.589 + 0.078778V)$$

where V is mean A / D converting simulating voltage.

NUMERICAL MODEL

In order to predict air-motion in the bell type swirl chamber, a numerical model of flow in the swirl chamber had been established.

(1) The Main Hypotheses

(a)The air-motion in the bell type swirl chamber is two dimensional.

(b)Turbulence: A modified K-ε turbulence model is used.

(c)Boundary condition: at the wall surface, the velocity distribution agrees with the 1 / 7 power law.

(2)Aerodynamic Equations

Continuous equation for cell m is:

$$\frac{\delta \rho_m}{\delta t} + \nabla \cdot (\rho_m u) = \nabla \cdot \left[\rho D \nabla \left(\frac{\rho_m}{\rho}\right)\right] \qquad (1)$$

where ρ_m is mass density of m; ρ is total mass density; u is air velocity; D is the diffusivity of m. The momentum equation for the fluid mixture is:

$$\frac{\delta(\rho U)}{\delta t} + \nabla \cdot (\rho u u) = -\frac{1}{\alpha^2} p - A_0 \nabla(2/3\rho K) + \nabla \cdot \sigma + \rho g \qquad (2)$$

where p is air pressure; α is undimensional value; $A_0 = 0$ if the flow is laminal and $A_0 = 1$ if the flow is turbulent; σ is the viscous stress tensor given by:

$$\sigma = \mu[\nabla u + (\nabla u)^T] + \lambda \nabla \cdot u Q \qquad (3)$$

where Q is the unit dyadic.

The internal energy equation is:

$$\frac{\delta(\rho I)}{\sigma t} + \nabla \cdot (\rho u I) = -p \nabla \cdot u + (1 - A_0)\sigma : \nabla u - \nabla \cdot J + A_0 \rho \varepsilon \qquad (4)$$

where I is the specific internal energy of the fluid (chemical energy exclusive); J is the heat flux vector given by:

$$J = -K \nabla T - \rho D \sum_m h_m \nabla(\rho_m / \rho) \qquad (5)$$

where T is the absolute temperature and h_m is the specific enthalpy of cell m.

The state relations for ideal gas are:

$$p = R_0 T \sum_m (\rho_m / W_m) \qquad (6)$$

$$I(T) = \sum_m (\rho_m / \rho) I_m(T) \qquad (7)$$

$$C_p(T) = \sum_m (\rho_m / \rho) C_{pm}(T) \qquad (8)$$

$$h_m(T) = I_m(T) + R_0 T / W_m \qquad (9)$$

where Im(T) is the specific internal energy for cell m; $C_{pm}(T)$ is the specific heat at constant pressure for cell m; W_m is the molecular weight of cell m; R_0 is the universal gas constant.

The transport coefficients are:

$$\mu = (1.0 - A_0)\rho v_0 + \mu_{air} + A_0 C_\mu k^2 / \varepsilon \rho \qquad (10)$$

$$\lambda = A_3 \mu \qquad (11)$$

$$K = \frac{\mu C_p}{P_r} \qquad (12)$$

$$D = \frac{\mu}{\rho S_c} \qquad (13)$$

Where v_0 is a constant decided by uniform background turbulent diffusivity; $\mu_{air} = A_1 T^{3/2}(T + A_2)$, where A_1 and A_2 are constant, $A_3 = 2/3$ if the flow is turbulent, P_r is the Prandtl number and S_c is the Schmidt number.

This numerical model could be used to calculate the flow in various type swirl chamber. In this paper, only the flow in the bell type swirl chamber during the compression stroke was calculated. The bell type swirl chamber was divided into 22 * 19 cells (Fig.3)

CALCULATED RESULTS

Fig.4 shows the calculated results of the flow in whole bell type swirl chamber with 40 ° inclination angle of connecting throat.

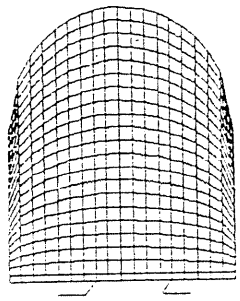

Fig.3 The meshed grid of the swirl chamber

During the compression stroke period, the flow velocity in the swirl chamber goes up with the crank angle increasing. The velocity increases rapidly after about BTDC 130℃ A. The velocity in the connecting throat achieves maximum one at BTDC23℃ A, and at TDC it drops down to zero. In this working period the flow in the bell type swirl chamber center is more powerful than that in the other area. There is a flow detention area in the up-stream side near the wall due to the friction between the air and the wall. In additoin the position of vortex core in the swirl chamber moves towards the left-below gradually with crank angle rising from BTDC100℃ A to TDC and it is under the center of the swirl chamber at last. As shown in Fig.4, there are two subvortex at the corner of the bell type swirl chamber. This agrees with the results of water-simulation [2].

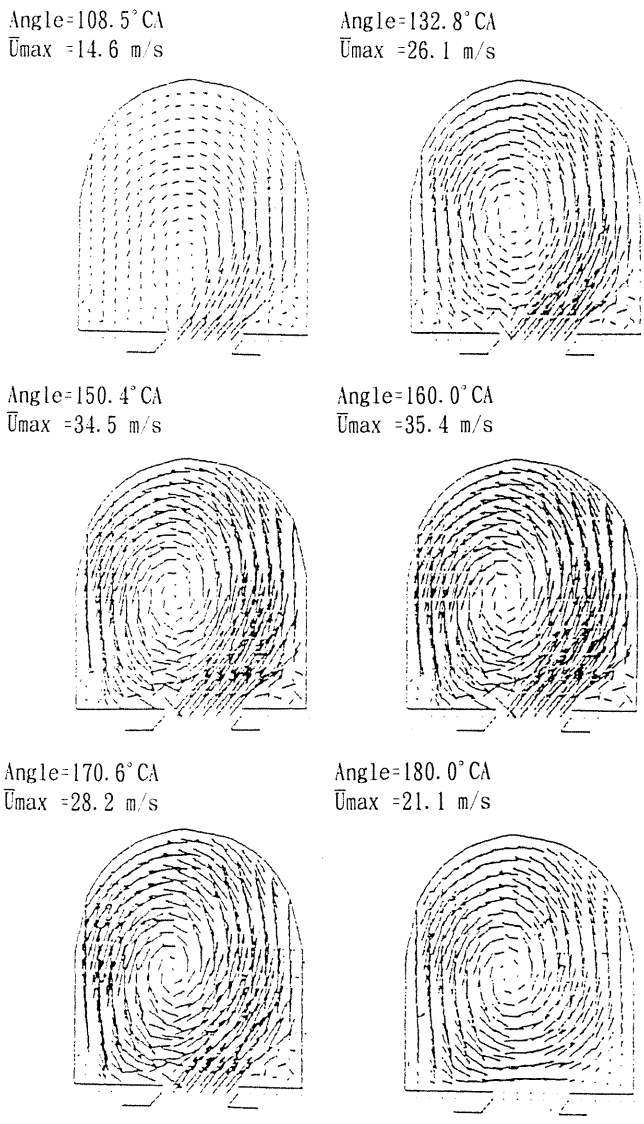

Fig.4 The calculated results

ANALYSIS OF RESULTS

Fig.5 shows that the velocity in point 1 and point 2 locates at $r / r_0 = 0.7$(where r_0 is radius of the swirl chamber) of the bell type swirl chamber change with the crank angle. There the actual line denotes the measured results and the dotted line denotes the calculated results and the dotted line denotes the calculated results. Two curves have the same shape and nearly same value. The maximum velocity in point 1 occurs at BTDC23℃ A (the calculated value U_{max} is 38.3m / s and the measured value U'_{max} is 35.4m / s). In point 2 the maximum velocity occurs at BTDC10℃ A (the calculated vcalue U_{2max} is 21.2m / s and the measured value U'_{2max} is 18.6m / s)

Fig.6 shows the meaured and calculated velocity U change along the r / r_0 at BTDC20℃ A and at TDC. The maximum velocity occurs between $r / r_0 = 0.7$ and 0.9. When the crank angle increases from BTDC20℃ A to TDC, the maximum volecity position moves towards the center of the chamber. Comparing the measured results with calculated ones in Fig.6a and Fig.6b, the two results show fairly good agreement.

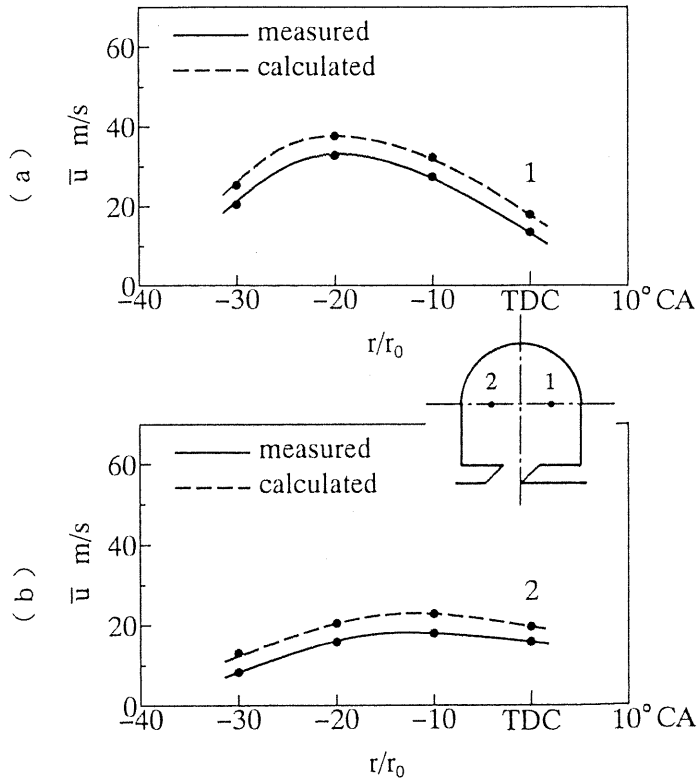

Fig.5 The velocity of flow changes with crank angle

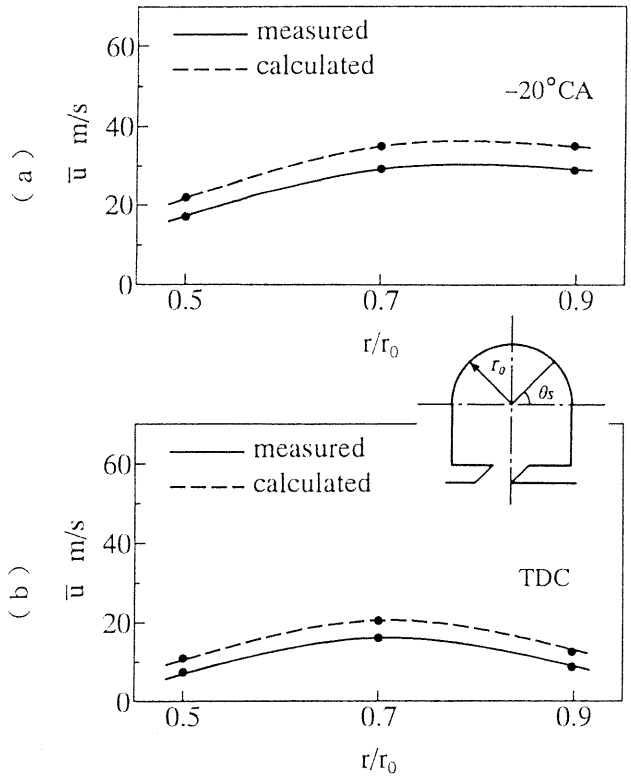

Fig.6 The velocity changes with r / r_0

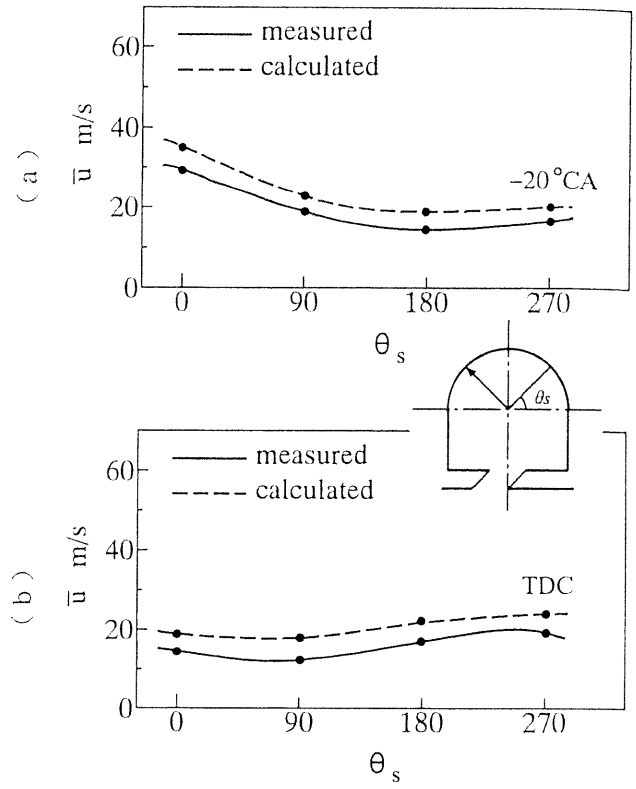

Fig.7 The distribution of the flow with θ_s

Fig.7 shows the distribution of velocity along $r / r_0 = 0.7$ circular in the bell type swirl chamber at TDC and at BTDC20℃ A. The angle θ_s mominates the position. The mean velocity achieves maximum when $\theta_s = 0$ at BTDC20℃A. The measured U_{max} is 33.5m / s and the calculated U_{max} is 29.8m / s. When $\theta_s = 0$ the concerned point locates near the connecting throat and is directly influenced by the flow through the throat from the main chamber, especially at BTDC20℃ A. When θ_s goes up to 90 °, U achieves its low limit and then keeps constant. At TDC U keeps a steady value because the air velocity in the connecting throat is nearly zero, shown in Fig.7b clearly.

CONCLUSIONS

(1) In compression process, the tangential velocities in the bell type swirl chamber vary with the crank angle. The velocity in the upstream side goes up with rising of the crank angle. At BTDC23 ° the velocity gets maximum value. In the downstream side velocities nearly keep constant after BTDC20 ° and is lower than in upstream side. There are two subvertexes in the corners of the chamber.

(2) In compression process, there are strong vortex motion. In the half compression period, it is a quasi-solid vortex, then changes to quasisolid vertex in the end of the compression period. The vertex core is located near the chamber center at the begining and in the middle of the compression stroke, then moves down left and at TDC it reaches the down-center of the chamber.

NOMENCLATURE

λ——laser light wave length, mm
α——laser beam intersection angle, deg
F_d——Laser Doppler frequency, Hz
V_f——the velocity of soot, m / s
V——mean A / D converting simulating voltage, V
ρ_m——mass density of m, kg / m^3
ρ——total mass density, kg / m^3
U——air velocity, m / s
D——the diffusivity, m^2 / s
P——pressure, N / m
σ——the viscous stress tensor
Q——the unit dyadic
I——the specific internal energy, J
J——the heat flux vector
T——the absolute temperature, K
h_m——the specific enthalpy of cell m, KJ / kg • k
$I_m(T)$——the specific internal energy for cell m, kJ / kg • K
$C_{pm}(T)$——the specific heat at constant pressure for cell m, kJ / kg • K
W_m——the molecular weight of cell m
R_0——the universal gas constant
v_0—— constant
μ_{air}——diffusivity of the molecular, m^2 / s
A_0, A_1, A_2, A_3——constant of the model
P_r——the Prandtl number
S_c——the Schmidt number

r——radius coodinate
r_0——radius, mm
U_{max}——the maximum flow velocity, m / s
θ_s——angle, deg
∇——Hamilton operator

Subscrip
air——air flow
$\sum$——total
m——cell m

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