EXPERIMENTAL RESEARCH INTO TURBULENCE FIELD IN COMBUSTION CHAMBER OF INTERNAL COMBUSTION ENGINE

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Abstract

The results of research into the velocity field in combustion chamber of piston engine are presented in the paper. The measurements of charge flow velocity in the cylinder axis and near the cylinder squeezing surface in several points were performed. The measurement results were used for analysis of turbulence field in examined combustion chamber. The turbulence field turned out to be inhomogeneous in the combustion chamber.

The test stand, measurement system, measurement results, configuration of measurement points in combustion chamber of research engine, charge instantaneous velocity variation curve in the ignitron points of the research combustion chamber, turbulence intensity variation curve in ignitron points, mean velocity, mean velocity fluctuations and velocity random component variation curve, comparison of charge flow mean velocities, comparison of velocity fluctuations in research combustion chamber in four measurement points, velocity fluctuation for two perpendicular directions have been introduced in the paper. The thermoanemometric measurements showed that there exists significant inhomogeneity of turbulent flow field in the engine combustion chamber. Areas of considerably diversified turbulence exist in the engine cylinder. The biggest turbulence in the researched engine is observed in the area between 5 and 15 mm from the head surface. Higher values of turbulence parameters occur in the area localized near the squish surface of the piston.

Keywords: *piston engine, combustion chamber, velocity field, turbulence*

1. INTRODUCTION

The research into charge flow field in combustion chamber of piston engine can be the source of valuable information for better knowledge concerning phenomenon taking place in the piston engine. It has been proved many years ago, that the swirl of fresh charge in the cylinder of piston engine has a direct impact on charge preparation to combustion and significantly influences the initial geometric shape of flame kernel in spark ignited engines. Better repeatability of flame front propagation in combustion chamber occurs in engines with adequate charge turbulence level before the initiation of combustion. In consequence it leads to lower non-repeatability of following engine cycles, which is the most important in engines combusting lean mixture. The combustion process in such engines is characterized by low flame front propagation velocity and the great non-repeatability of following engine cycles.

2. THE TEST STAND

The research was conducted on a single-cylinder S320 test engine working at 1000 rev/min. The compression ratio of the engine is 8.5. The head is design in a four-valve system and allows installing up to 9 spark plugs. Two of the spark plug seats are used as pick-up seats. One of them was localized in the axis of the cylinder and the other one was localized near piston squish surface. The measurements were conducted with fully open throttling valve. The combustion engine was equipped with electric engine working as a prime mover. The measurements were conducted on the engine driven without supplying fuel.
The test stand consisted of:

- Single cylinder S320 test engine,
- Electric engine working as a prime mover,
- Air flow through engine measurement system consisting of Roots flowmeter and equalizing tank of volume equal 1.5 m^2,
- Digital data acquisition system for fast-changing pressure in engine cylinder recording,
- Kistler CAM 2611 digital crank angle transducer,
- FMC 921 thermoanemometric extension card,
- Thermoanemometric pick-ups for in-cylinder flow velocity measurement equipped with adaptors designed to mount the pick-ups in spark plug seats.

Pressure recording system

- Piezoelectric pressure pick-up - Kistler SN 6061,
- Charge amplifier - Kistler 5011,
- Digital crank angle transducer - Kistler CAM 2611
- Oscilloscope - HAMEG HM 203-7,
- 12-bit, eight-channel analogue-digital converter extension card - AMBEX LC-020-812,
- IBM PC/AT computer,
- "LCTXR" software designed for data digital recording.

The software designed for data digital recording [7] and the necessity of registering five channels simultaneously allowed to register 40 cycles maximum.

The thermoanemometric pick-up in X configuration with perpendicular sensors was used in order to measure the charge flow velocity.

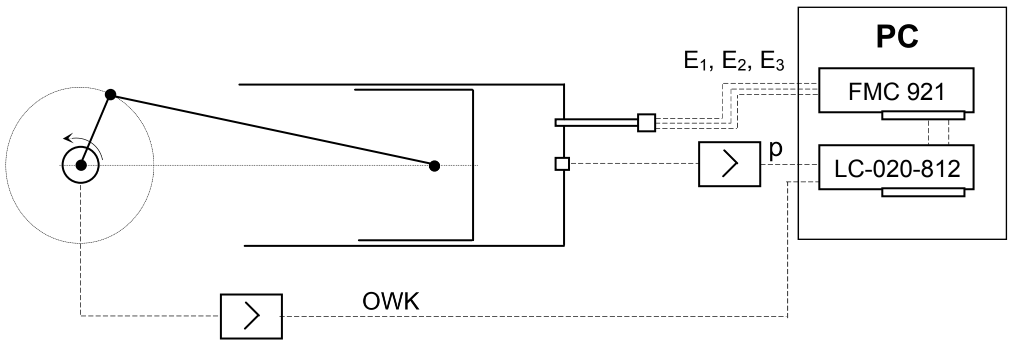

Fig. 1.Measurement system diagram

The thermoanemometric extension card FMC 921 adapted to the pick-ups was used in the measurement system. Using such measurement system allowed to record and store measurement data directly in the PC computer. The software realized the calculation algorithm on the basis of registered signals. The measurement extension card is equipped with two thermoanemometric sets and one thermometer set.

3. MEASUREMENT RESULTS INTERPRETATION

The instantaneous flow velocity of specific cycle can be set as a sum of mean velocities of all cycles, mean velocity fluctuation and random fluctuation of component velocity.

$$U(\varphi,i) = \overline{U}(\varphi) + \hat{U}(\varphi,i) + u(\varphi,i),$$

Where:

$\overline{U}(\varphi)$ - Mean velocity obtained by averaging by relation set,

$\hat{U}(\varphi,i)$	-	Mean velocity fluctuation,
$u(\varphi,i)$	-	Random fluctuation of component velocity.

In order to analyse the relation set, the flow velocity is given as a sum of mean velocity obtained by averaging the relation set regarding crank angle, rms value of mean velocity fluctuations and rms value of random velocity fluctuations.

$$U(\varphi) = \overline{U}(\varphi) + U_{RMS}(\varphi) + u_{RMS}(\varphi),$$

Where:

$\overline{U}(\varphi)$	-	Mean velocity obtained by averaging by relation set,
$U_{RMS}(\varphi)$	-	Rms value of mean velocity fluctuation,
$u_{RMS}(\varphi)$	-	Rms value of random fluctuation of velocity.

Mean velocity value for all analysed cycles:

$$\overline{U}(\varphi) = \frac{1}{N}\sum_{i=1}^{N} U(\varphi,i),$$

The mean velocity for the individual cycle $\overline{U}(\varphi,i)$ determined by filtering voltage signal obtained from the thermoanemometric system. The filtering was realized with the use of low-pass filter of experimentally selected limit frequency.

Fluctuation of mean velocity:

$$U_{RMS}(\varphi) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[\overline{U}(\varphi,i) - \overline{U}(\varphi)\right]^2},$$

Velocity fluctuation:

$$u_{RMS}(\varphi) = \sqrt{\frac{1}{N}\sum\left[U(\varphi,i) - \overline{U}(\varphi,i)\right]^2},$$

Turbulence intensity:

$$u'_{RMS} = \frac{u_{RMS}}{c_m}$$

The mean velocity $\overline{U}(\varphi,i)$ in the analysed cycle can be presented as a sum of mean velocity of all cycles $\overline{U}(\varphi)$ and mean velocity fluctuation $\hat{U}(\varphi,i)$

$$\hat{\overline{U}}(\varphi,i) = \overline{U}(\varphi) + \hat{U}(\varphi).$$

Such presentation of charge flow velocity in piston engine cylinder gives the value, which is the most consistent with variations of velocity in real conditions. It gives information concerning mean velocity of all cycles, mean velocity fluctuations and fluctuation of velocity responsible for turbulence generation inside the engine cylinder.

4. Measurement results

The presented results were obtained on the basis of measurements using single pick-up in the combustion chamber. The measurements were performed three times using the same pick-up. This allowed the influence of changes in pick-up measurement capabilities in the first stage of its application on obtained results to be minimized. Before the first use of the pick-up it was hold at the temperature of 500°C in the stream of air according to the manufacturer's recommendations. The measurements were also performed with the use of other pick-ups of the same type.

The flow field measurements were done in six points in the combustion chamber. Each point was 5 mm away from the other, fig. 2. The ignition in working engine occurs in point A.

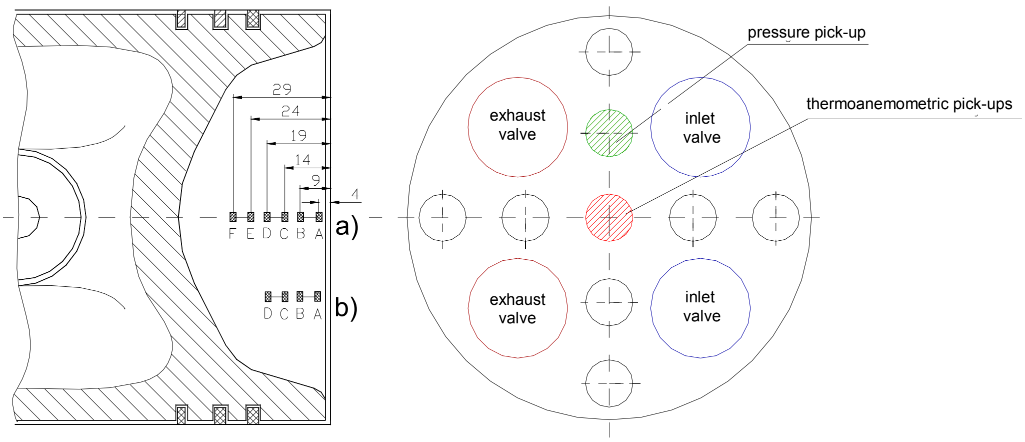

Fig. 2. Configuration of measurement points in combustion chamber of research engine.

Fig. 3. depicts the instantaneous velocities in the following engine cycles. The high non-repeatability can be observed in the cylinder axis as well as near the squish surface of the piston. Velocities measured in the cylinder axis are shown in a) and velocities measured near the squish surface are shown in b).

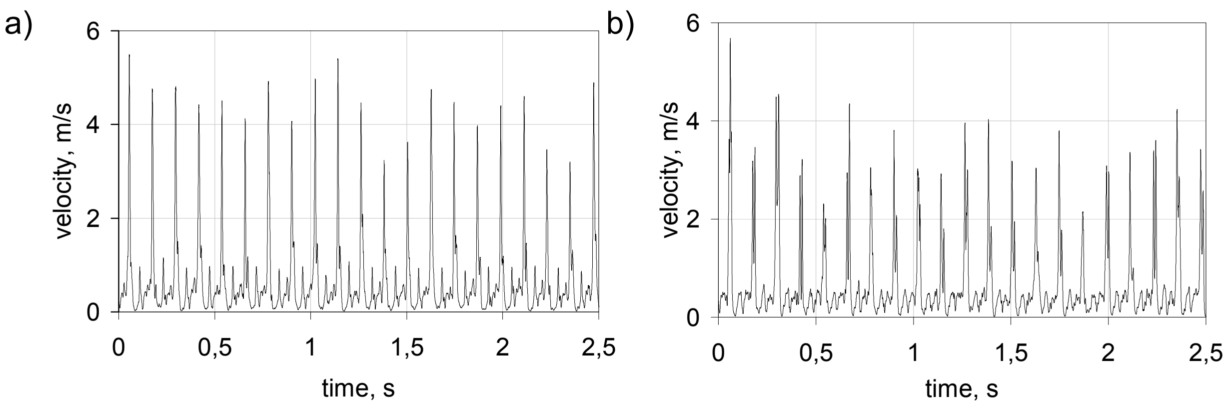

Fig.3. Charge instantaneous velocity variation curve in the ignitron points of the research combustion chamber

a) b)

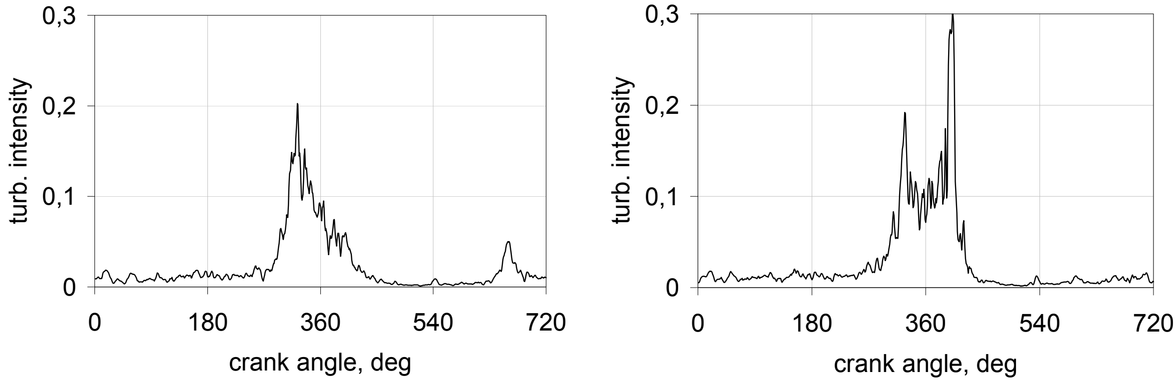

Fig.4. Turbulence intensity variation curve in ignitron points

The turbulence intensity gains its maximum 35°CA before TDC. Two local maximums occur near the piston squish surface. It is caused by the charge return flow resulting from the piston movement in the direction of BDC.

Digital filtering of recorded signals determines the mean velocity of the individual cycle. The low-pass filter and LCT [7] program were used to do so. Normalized limit frequency in the range of 18÷21 was determined. The harmonic of 18÷21 rank determine the mean velocity as the higher harmonics determine the velocity fluctuation.

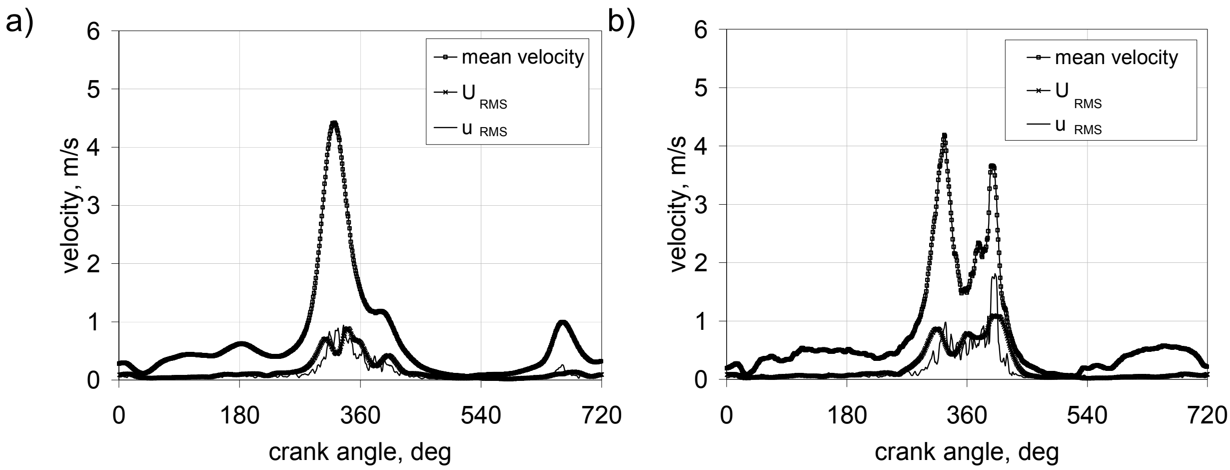

Fig.5. Mean velocity, mean velocity fluctuations and velocity random component variation curve

Fig. 5 shows the mean velocity obtained as a result of averaging the mean velocity fluctuation and RMS value of velocity random component for 40 following cycles regarding the crank angle. The mean velocity fluctuation informs about the variations of mean velocity in the following cycles of engine work. It can have significant influence on engine work non-repeatability as different flow conditions in following cycles occur in the ignition region

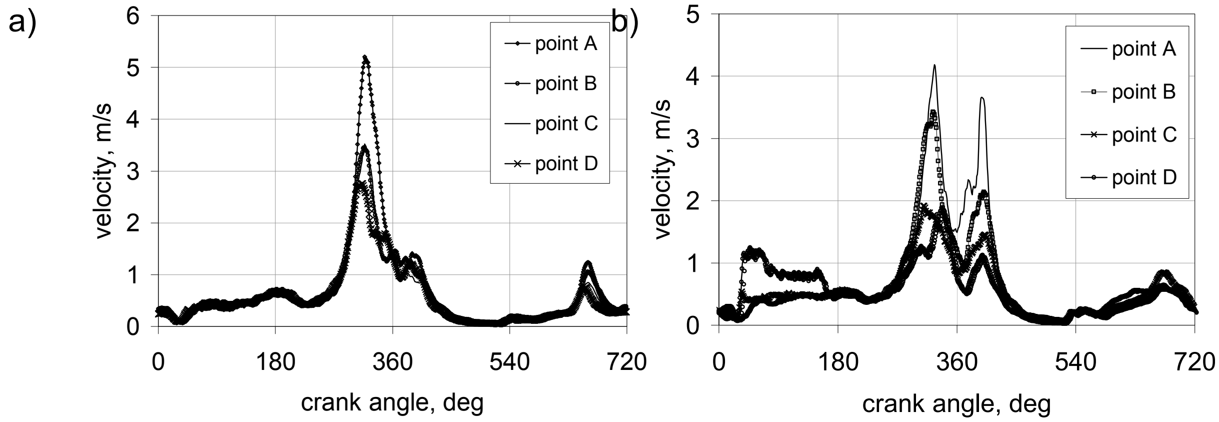

Fig. 6. Comparison of charge flow mean velocities

The type of measured velocity variations near the piston squish surface reveals the direct influence of piston squish. The charge flow in the direction of the centre of combustion chamber occurs in the initial phase before 330°CA. After that there exists the retention of charge flow and then the charge begins to flow from the centre of the combustion chamber to the direction of cylinder walls. The thermoanemometric measurement method allows obtaining the absolute values of flow velocity. That is why two maximums can be seen in the flow velocity graphs. The change in the velocity sense occurs later in the measurement points located further from the head surface because the squish process starts later there.

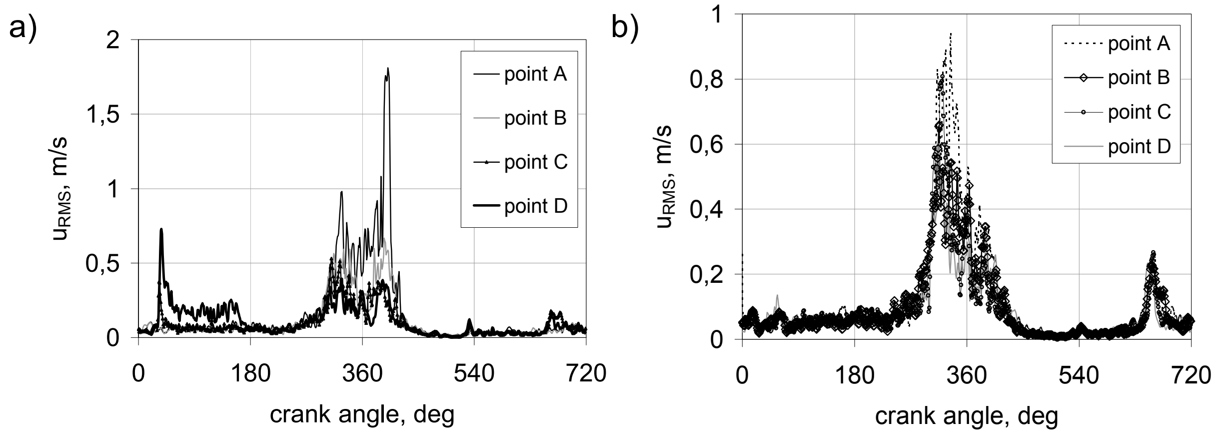

Fig. 7. Comparison of velocity fluctuations in research combustion chamber in four measurement points

The presented measurement results show that the flow processes in the researched combustion chamber occur in the most intensive way near the engine head. Both the flow velocity and the charge turbulence parameters begin to increase after 270°CA and gain the maximum near 35°CA before TDC. It can be stated on the basis of analysis of turbulence intensity obtained in the following measurement points, that the highest turbulence occurs in the combustion chamber axis about 10 mm from the engine head. The turbulence is lower in the points located deeper in the combustion chamber.

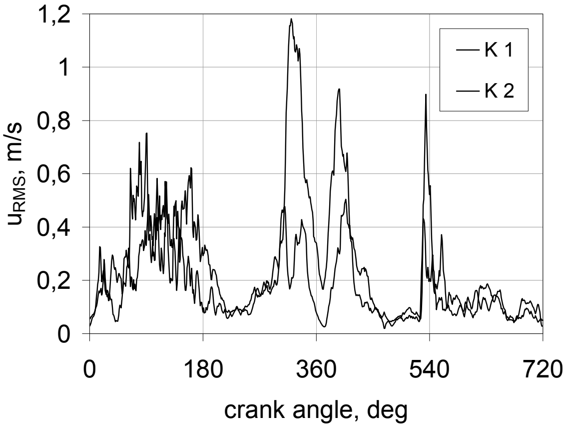

Fig. 8. Velocity fluctuation for two perpendicaular directions

The performed research proved that the generated charge turbulence in the ignition region at the time of intake stroke does not have a significant influence on the turbulence value at the time of compression stroke. After intake valves closure there exists the increase of charge turbulence caused by the generated macro-swirl and the charge flow from the area of piston squish surface to the cylinder centre. The high turbulence value in the region of ignition a few CA degrees before TDC is important regarding the engine work quality. The charge turbulence, which is generated during the intake stroke in the research engine, is also important regarding the engine work. The mixing of fuel and air occurs at that time, which is charge preparation to be combusted. Homogeneity of air-fuel mixture leads to better combustion and as a consequence to the decrease in toxic components concentration in exhaust gases and increase in engine work parameters.

5. Conclusions

The measurements of velocity variations of charge inside the engine combustion chamber revealed high non-repeatability of these variations in the following cycles. The non-repeatability occurred in the aspect of the velocity values as well as the aspect of crank angle corresponding with the maximal value. The maximal velocity dispersion in the researched engine was in the following cycles at the level of 2 m/s, which is 35% of the velocity maximal value. The thermoanemometric measurements showed that there exists significant inhomogeneity of turbulent flow field in the engine combustion chamber. Areas of considerably diversified turbulence exist in the engine cylinder. The biggest turbulence in the researched engine is observed in the area between 5 and 15 mm from the head surface. Higher values of turbulence parameters occur in the area localized near the squish surface of the piston.

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