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The Influence of Piston Internal Combustion Engines Intake and Exhaust Systems Configuration on Local Heat Transfer

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Abstract

The improvement of work processes of piston engines to boost the technical and economic parameters is the main objective in the field of power engineering. The improvement of the gas exchange processes (intake and exhaust processes) quality is one of the possible profiles to improve the efficiency and reliability of piston internal combustion engines. The study of the instantaneous local heat transfer at flow unsteadiness is one of the objectives of the experimental studies of the thermomechanical processes in the intake and exhaust systems of the engines. The influence of configuration of the intake and exhaust pipes on the heat transfer intensity is a relevant engineering problem. The local heat transfer intensity data serves as the basis to determine the basis for determination of heating of the air (at intake), cooling exhaust gas (at exhaust), calculation of thermal stresses in the nodes and details of intake and exhaust systems. The article presents the results of the experimental investigation of the instantaneous local heat transfer (taking into account the hydrodynamic nonstationarity) in the intake and exhaust pipes of different configurations for piston internal combustion engines. It is established that the cross profiling of the intake and exhaust pipes of piston engines leads to 5-20% decrease in the local heat transfer intensity depending on the crankshaft speed.

Keywords: piston engines; gas exchange processes; intake and exhaust pipes; cross profiling; local heat transfer; process improvement.

1. Introduction

The improvement of work processes of piston engines with the aim of improving technical and economic indicators is an important task in the field of engine and energy. The improvement of the quality of gas exchange processes (intake and exhaust processes) is one of the possible directions of increase of efficiency and reliability of

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piston internal combustion engines. In particular, the limited amount of information in the Russian and foreign literature can be found about the studies of heat transfer in the intake and exhaust pipes. Apparently, this can be explained by the fact that the gas exchange processes in piston internal combustion engines are unsteady and high-frequency processes, this greatly complicates scientific approaches to their study. Data about intensity of the instantaneous heat transfer are the basis for determination of heating of the air (at intake), cooling exhaust gas (at exhaust), calculation of thermal stresses in the nodes and details of intake and exhaust systems. However, data on instantaneous heat transfer is practically absent, so engineering calculations are performed on the basis of data on stationary flows. It is known that the heat transfer coefficient in unsteady conditions may differ from the stationary case in 2-4 times [1-6].

Results of experimental investigation of the instantaneous local heat transfer (taking into account the hydrodynamic nonstationarity) in the intake and exhaust pipes of different configurations for piston internal combustion engines are presented in this article.

Nomenclature

ICE	internal combustion engine
TDC	top dead center
BDC	bottom dead center
φ	crank angle, degrees
n	engine crankshaft rotation frequency, rpm
w_x	local speed of gas flow, m/s
α_x	local heat transfer coefficient, $W/(m^2 \cdot K)$
p_b	pressure at the end of exhaust process, bar
d	channel diameter, mm
d_e	equivalent hydraulic diameter, mm
l_x	linear dimension, mm

2. Experimental setups and measurement equipments

The experimental setups for the experimental investigation of local heat transfer in the intake and exhaust pipes were designed and manufactured. They were a full-scale model single-cylinder engine of 8.2/7.1 dimension. The valve timing mechanism for experimental setups was used from the VAZ-OKA engine. The periods of valve timing and valve lift for setups were in accordance with the one for this engine. An induction motor drives the rotation of the crankshaft of the experimental setups. The frequency Converter regulates the rotation speed of the crankshaft in the range from 600 to 3000 rpm. Detailed description of the experimental setups presented in [7].

Automated system for the collection and processing of experimental data was developed on the basis of the analog-to-digital Converter. This system was sending experimental data to the computer for processing. The constant temperature anemometer [8] was used to determine the flow rate of air (w_x) and the local heat transfer coefficient (α_x). The sensitive element of the anemometer sensor was nichrome filament which had a diameter of 5 μm and length of 5 mm. Measurement of rotation frequency and the position of the engine crankshaft is produced by the tachometer. The position of the piston at the top and bottom dead points is determined on the basis of this data.

3. The instantaneous local heat transfer in the intake pipe

It is known [9-12], that one of the ways to improve gas dynamics in intake and exhaust pipes is a cross profiling of the channels. Cross profiling of the channels leads to a significant change in gas dynamic parameters of the flow in the piping, this could also affect a change in the local heat transfer coefficient.

The studied configuration of the intake system and location of sensors are presented in Fig. 1.

Intake pipes with a cross-section in the shape of a circle, square and equilateral triangle were used in this study. A profiled section made up approximately 30 % of the total length of intake system. The equivalent (hydraulic) diameter d_e was equal to 32 mm for the intake pipe.

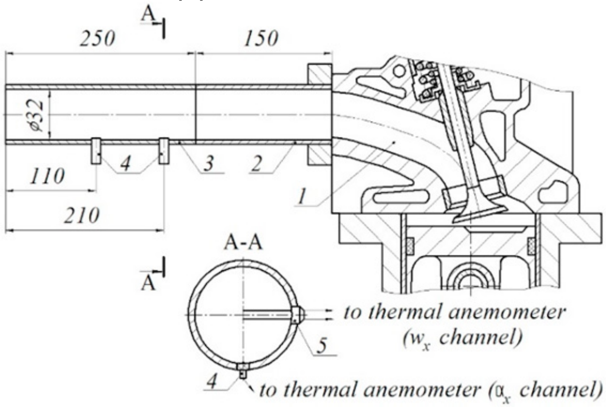

Fig. 1. The intake system of the experimental setup: *1* – channel in the cylinder head; *2* – intake pipe (profiled section); *3* – measuring channel; *4* – thermal-anemometer sensor to determine the local heat transfer coefficient; *5* – thermal-anemometer sensor to determine the velocity of flow

The dependences of the instantaneous local heat transfer coefficient α_x from the crankshaft rotation angle φ in the intake system with different configurations of channels are shown on Fig. 2.

From the presented data, it is seen that the mechanism of changes in the local heat transfer coefficient is stored for all configurations of intake pipes: the area of the beginning and end of a significant change in heat transfer α_x, the region of maximum values of heat transfer α_x, the change curve of heat transfer $\alpha_x = f(\varphi)$.

It should be noted that the maximum value of local heat transfer coefficient is somewhat smaller when using profiled sections. This is especially true for pipes with triangular cross section compared to the intake system with a circular cross section. The largest decline of heat transfer is observed for high values of the crankshaft rotation frequency (the differences are about 10-20 %). A ratio of the intensity of heat transfer is typical for all studied conditions.

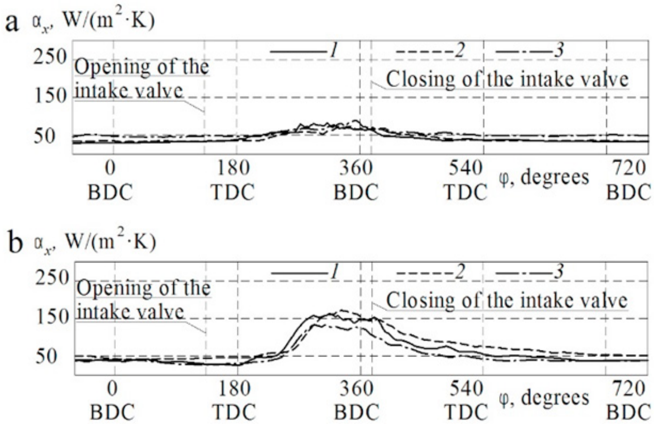

Fig. 2. The dependences of the instantaneous local (l_x = 110 mm, d = 32 mm) heat transfer coefficient α_x from the crankshaft rotation angle φ in the intake system with different configurations for different crankshaft rotation frequencies n: a – n = 600 rpm; b – n = 3000 rpm
The cross-section of pipes: 1 – circle; 2 – square; 3 – triangle

The influence of the cross-section shape of the intake pipe is virtually absent at low crankshaft rotation frequencies (Fig. 2, a); the variation of the local heat transfer coefficient for all configurations of the pipes is within systematic errors of measurement. The more significant differences of heat transfer coefficients are observed at high crankshaft rotation frequencies (Fig. 2, b).

It can be concluded that the cross profiling of the intake pipe of the internal combustion engine reduces the intensity of the local heat transfer. Thus, it is possible to control the thermal flow characteristics in the intake system of the engine. Ceteris paribus, reducing of the intensity of heat transfer should have a positive impact on the engine work processes and, in particular, on the air cylinder filling. The decrease in the intensity of heat transfer will lead to less heating of air from the walls of the intake pipe. Consequently, the mass filling of the cylinder will increase due to the higher air density.

It should also be noted that the decrease in the intensity of local heat transfer in the intake pipe with a profiled section may lead to decrease in thermal stresses in the intake system as a whole. Consequently, the reliability of the elements of the intake system of the piston internal combustion engine will increase.

4. The instantaneous local heat transfer in the exhaust pipe

The analysis of gas dynamics and local heat transfer in the exhaust pipe of a circular cross-section of piston internal combustion engines showed that the gas dynamics of the exhaust process is varied with the increasing speed of the crankshaft and the flow regime (flow structure) is changed also [13-15]. Accordingly, this leads to a transformation of dependence of the local heat transfer coefficient from the angle φ. It is also established that a high level of intensity of heat transfer is in the exhaust pipe of the piston internal combustion engine. Therefore, it is necessary to reduce the intensity and pulsations of the local heat transfer α_x to reduce thermal stress of the exhaust system and the cylinder group of the internal combustion engine [16-18].

The study of the exhaust process was carried out at different engine speeds from 600 to 3000 rpm and under constant pressures at the end of exhaust process, which were varied from 0,5 to 2,0 bar. The air temperature in the supply line was 35-45 ^{o}C.

Channels with a cross-section in the shape of a circle, square and equilateral triangle were also used in this study to improve the heat transfer processes in the exhaust system. A profiled section made up approximately 30 % of the total length of exhaust system. The equivalent (hydraulic) diameter d_e was equal to 30 mm for the exhaust pipe.

The configuration of the exhaust system and location of sensors are shown in Fig. 3.

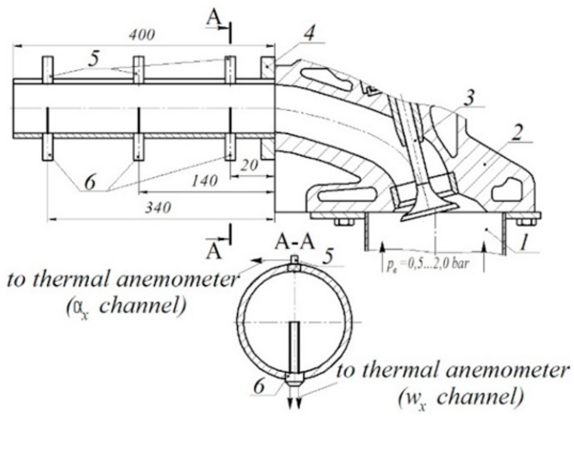

Fig. 3. The exhaust system of the experimental setup: *1* – engine cylinder; *2* – cylinder head; *3* – exhaust valve; *4* – exhaust pipe; *5* – thermal-anemometer sensor to determine the local heat transfer coefficient; *6* – thermal-anemometer sensor to determine the velocity of flow
The cross-section of pipes: 1 – circle; 2 – square; 3 – triangle

In order to evaluate the degree of influence of the profiled sections in the exhaust pipe please refer to Fig. 4. The dependences of the instantaneous local heat transfer coefficient α_x in the exhaust pipes of different cross-section from the crankshaft rotation angle φ for the crankshaft rotation frequency n = 1500 rpm and at different an initial excess pressure (1,0 bar and 2,0 bar) are shown on this figure.

It is established that the mechanism of change of the local coefficient of heat transfer in profiled exhaust pipe and exhaust pipe of constant circular cross-section are identical (Fig. 4). It should be noted, the growth and decline of the local heat transfer coefficient α_x in the exhaust pipes of different configurations at all crankshaft rotation frequencies n and exhaust pressures p_b occur at about the same the crankshaft rotation angles φ. The period of growth of the intensity of the local heat transfer is approximately 150 to 290 degrees, and the period of decline is in the range of φ from 290 to 430 degrees.

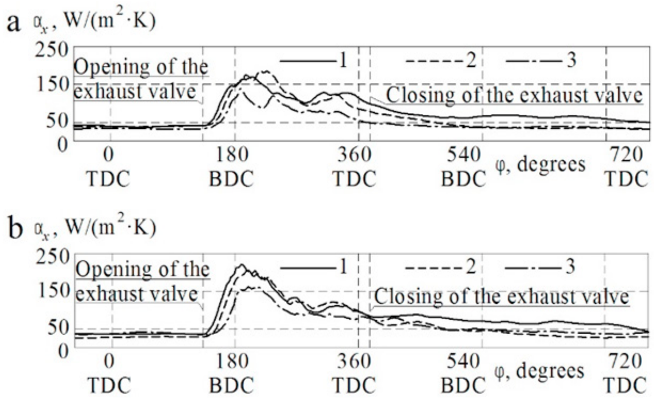

Fig. 4. The dependences of the instantaneous local (l_x = 140 mm, d = 30 mm) heat transfer coefficient α_x in the exhaust pipes of different cross-section from the crankshaft rotation angle φ for the crankshaft rotation frequency n = 1500 rpm and at different an initial excess pressure p_b: a – 1,0 bar; b – 2,0 bar
The cross-section of pipes: 1 – circle; 2 – square; 3 – triangle

From Fig. 4 it is seen that the intensity of the heat transfer in the exhaust pipe of a circular cross section and in the pipe with a plot with a square cross section are essentially the same. (the differences are about 10-15 % and are within the error). This is true for all values of initial exhaust pressure and all frequencies of the crankshaft.

It is established that the intensity and maximum values of the local heat transfer coefficient in the exhaust pipe with triangular cross section are reduced; reduction of heat transfer α_x is in the range of 10-25 % at engine speeds from 600 to 1500 rpm and about 20% at n = 3000 rpm.

The discovered effect indicates that less heat "goes" in the pipe wall when using exhaust pipe with a profiled section in the shape of an equilateral triangle. Accordingly, the heat intensity of elements of the exhaust system is reduced. Also, the efficiency of the exhaust flow in the turbine of the turbocharger in an engine with a supercharger is increases.

It should be noted that the curve $\alpha_x = f(\varphi)$ in the exhaust pipe with profiled areas is more smooth compared to pipe of constant circular cross-section.

5. Summary

Experimental study showed that cross profiling of the intake and exhaust pipes has a significant impact on the gas dynamics and heat transfer of gas exchange processes.

It is established that the cross profiling of the intake pipe of the engine leads to a decrease in the intensity of local heat transfer in the range of 5-20%, depending on the crankshaft speed. This causes the following effects:

- heating of the air (at intake) is reduced on average by 30 %; this leads to improved cylinder filling due to the increased density of the air;
- thermal stresses of parts of the intake system is reduced; accordingly, this will increase their reliability (dependability).

It is also established that the cross profiling of the exhaust pipe of the piston engine leads to a decrease the intensity of local heat transfer by up to 30 %. This causes the following effects:

- the efficiency of the exhaust gas in the turbine of the turbocharger is increased, because less heat "goes" into the wall of exhaust pipe;
- the thermal stresses in the major elements of the exhaust system are reduced.

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