INTERNAL COMBUSTION MICRO-CHAMBERS AND MICRO-ENGINES

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Abstract

Technological progress caused miniaturization of internal-combustion engines. They found application in many areas. The acquaintance of the ignition and combustion processes in the small volumes, the solution of the problem of piston movement under the influence of a pulse combustion in chambers, the choice of materials and problems related with the mixtures and exhaust creation, all these issues require a exact acquaintance for the purpose of optimization of the micro engine performance. In the paper some issues are talked over on the base of investigations performed on the small volume chambers in single compression machines and in the shaftless two-cycle engine. Researched was the influence of the micro chamber size and of the area/volume ratio value on the processes of combustion occuring in the very small volumes and with the large values of area/volume ratio. Together with raise of the area/volume ratio, the value of the combustion pressure impulse becomes lower. The influence of the chamber material type on the combustion processes was defined, both in the single compression machine as in the micro engine. The existence of micro chamber size influence on the combustion limits of the fuel/air mixtures was designated. It has been determined that the range of the combustion limit is decreased with diminishing of the combustion chamber diameter, at the same time these changes are not the function of the area/volume ratio value changes. The maximum values of the combustion pressure appeared when chamber was supplied with stechiometric mixture, irrespective of the chamber dimensions.

Keywords: *internal combustion engine, micro engine, shaft less engine, combustion chamber*

1. Introduction

In recent years technological progress contributed to miniaturization of internal-combustion engines. They found a number of applications in the miniature systems. The fundamental virtue of micro engines is fact that they are powered with hydrocarbon fuels, which are characterized by the high accumulated energy density. They can be applied everywhere where essential is the longer time of activity, the small weight of power plant system and small outline dimensions. The one of the many applications is usage to power the small reconnaissance aircraft, to supply power for mini cameras and measuring transducers. They can be applied both to the military or civilian means.

At the moment in several leading centers in the world the micro combustion chambers and with internal combustion micro engines are developed, which perform with possible to the acceptance combustion efficiency. The idea of micro engine utilization to generation of electric current is relatively new and the various aspects of its practical realization are constantly researched.

In Massachusetts Institute of Technology in the Gas Turbines Laboratory is developed gas micro turbine is developed on the basis of the MEMS (Micro-Electro-Mechanical Systems) elements. It is planned to obtain 10 - 20 W of electric power from the 300 mm^3 volume of this unit.

In University of California, Berkeley in the Combustion Laboratory the internal combustion Wankel type micro engine is developed, supplied with liquid hydrocarbon fuel. The respective versions of this micro engine have the rotor diameters of 10 mm and 3 mm. Smaller from these micro engines has to develop power in the miliwatt range.

In the Honeywell company the micro engine is developed with free rotating piston, working on the basis of homogeneous mixture self ignition principle (HCCI). Engine with volume of 1000 mm^3 has to develop power in the 10 W range.

In Georgia Institute of Technology micro engine is developed with free moving piston. This piston is manufactured from ferromagnetic material. Displacing in the electromagnetic field with oscillatory movement it generates electric current with power of about 12 W.

2. Requirements

The basic attibutes of the micro engines besides very small dimensions is high temperature resistance, but that goes for this, the application of pottery materials, the minimum of moving parts, the high concentration of energy, the ignition from the plasma stream or self ignition, normal or catalytic combustion.

The specific of micro engines relies on the much more larger walls cooling effect on the course of all processes occurring there, than it takes place in conventional engines. Such processes how compression, ignition, combustion, expansion, but also the charge exchange, are found being under strong influence of this effect. In the engine with large ratio of combustion chamber area to its volume, the majority of these processes will depend strongly of combustion chamber geometry. In these engines the charge compression and combustion processes are particularly critical in comparison with the similar processes in conventional engines, considering large heat transfer to the walls and local extinguishing of flame. Both the results of experiments, like the conclusions resultant from the theory show, that for exothermic reaction course assurance the critical diameter is required with the sizes of the millimeter range. The current generated by micro engine will depend from the result of mutually neutralizing itself activities: heat transfer speed from the reaction micro region to the walls and the heat release rate from this reaction area. Both the charge compression process, like its combustion will be under the great influence of heat transfer to the walls.

It is roughly possible to estimate the influence of the object scale on the heat transfer intensity. The specific heat stream (related to the unity of mass) $\dot{q}$ from gas enclosed in volume V with area S can be expressed through the heat stream average density $\overline{q}$ and the average density $\overline{\rho}$ with the help of following formula:

$$\dot{q} = \frac{\dot{Q}}{m} \frac{\int_S q dS}{\int_V \rho dV} = \frac{\overline{q}}{\overline{\rho}} \frac{S}{V}, \tag{1}$$

where:

$\dot{Q}$ - the heat stream,

q - the heat stream density,

m - mass,

ρ - density.

From this equation results that specific heat stream $\dot{q}$ increases together with increase of the area to the volume ratio S/V of combustion space. This ratio is inversely proportional to the combustion chamber size. Thus, both the charge compression process, as charge combustion will be under the big influence of heat transfer to the walls. In micro chambers together with growth of

S/V ratio the value of the combustion pressure impulse becomes smaller. The improvement is the multipoint ignition usage, because of faster mixture combustion occurs, shorter time of heat loss to the walls, that causes the increase of the values of combustion pressure impulse.

With the lower values of S/V ratio the application of multipoint ignition plays the smaller role, because heat losses to the walls are smaller. The location place of catalytic igniter also influences on the value of the combustion pressure impulse. In of normal conditions for the hydrogen with air mixture the critical distance equals 0.6 mm but for the propane with air mixture the distance equals 2 mm. This distance depends on the type of mixture, temperature, pressure and on the chamber shape. Is necessary to take this distance into consideration because it is comparable with the combustion micro chambers dimensions. In micro engines applied to investigations the quenching distance for the propane flames was in the same order that the chamber diameter, but for the hydrogen flames it was several times smaller in comparison with the chamber diameter. Investigated was the influence of the thermal conductivity of materials from which the walls of combustion chamber were manufactured. The several different materials and the different of walls thicknesses were applied. From investigations results, that walls thermal conductivity in the single charge compression machine does not have any measurable influence on the course of compression and combustion pressures. The small differences in curves for different wall materials fit in the borders of the experiment error. These results suggest, that for single courses the chamber walls are isothermal and heat losses to the walls are not function of their thermal conductivity. This results from a small quantity of heat and of short time related with the combustion in the small volume. Also the walls thickness did not influence significantly on the course of the compression and combustion pressures. Otherwise influences thickness and the type of material in micro engines, for which combustion chamber walls thermal conductivity influences in fact on the course of pressure.

Other issue connected with the micro chambers application is the choice of a appropriate value of the fuel/air ratio. How investigations proved the combustion border in the small combustion chamber with big S/V ratio is narrowed and the combustion range is smaller than generally assumed. If the bottom combustibility limit in the case of micro chambers did not depend on the chamber dimensions and with even double increase of the chamber dimensions it was the same, the top combustibility limit depends on the chamber dimensions and for the larger chamber has some greater value. One should notice, that the maximum values of the combustion pressure occurred with supply of stechiometric mixture to chamber, irrespective of the chamber dimensions.

3. Model research engine with the free piston

The design of the prototype of a two-cycle shaftless engine is submitted on drawings 1-4. On Fig. 1 the schematic general view of the two-cycle shaftless engine prototype is shown. Fig 2 presents the sectional view of this prototype of engine along of longitudinal axis through one of the induction channels.

The elements of this prototype are, in the order: 1. piston, 2. cylinder, 3. head, 4. case, 5. glow head with the combustion chamber and catalytic igniter, 6. separator with the additional combustion chamber, 7. head encapsulation, 8. pressure pick up, 9. regulating spring, 10. starting tie rod, 11. regulating screw, 12. two induction channels, 13. exhaust channel.

On Fig. 3 are shown the basic elements of this engine: case, head with initial chamber and catalytic igniter, cylinder and piston with the starting tie rod, regulating spring and 1 eurocent for the comparison of size.

On Fig. 4 piston assembly and cylinder with the tubes of the engine induction system are shown.

Initial research of the prototype of a two-cycle miniature engine with free piston had on the aim the check of the values of compression pressure in the combustion chamber. The regulation of compression pressure was obtained in dependence on the regulating spring pre strain in the range from 5.4 to 5.9 bar. Exemplary graph of compression pressure is shown on Fig. 6. The higher compression pressure was obtained by setting the larger initial tension of the regulating spring.

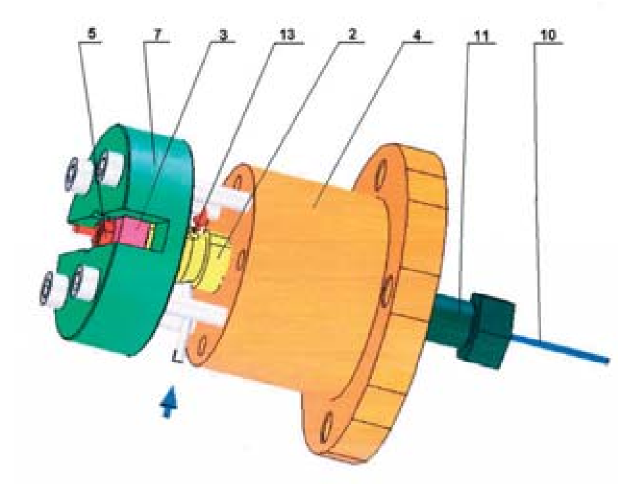

Fig. 1. General view of the two-cycle miniature shaftless engine prototype

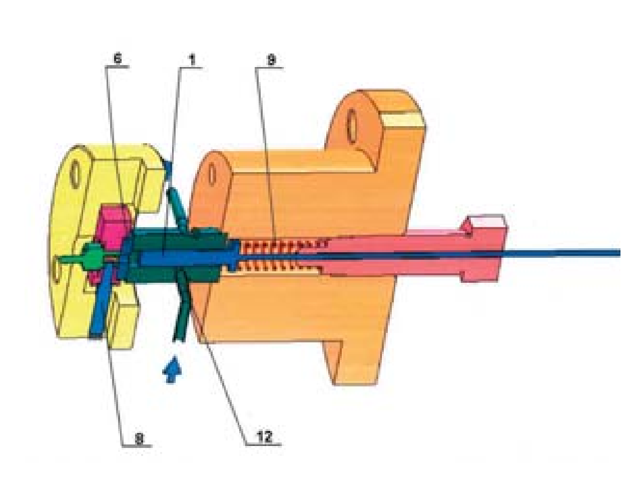

Fig. 2. Sectional view of the two-cycle miniature shaftless engine prototype along longitudinal axis through one of the induction channels

Fig. 3. View of the two-cycle miniature shaftless engine prototype basic elements

Fig. 4. View of piston and cylinder of the two-cycle miniature shaftless engine prototype

Block schema of the measuring system is submitted on Fig. 5.

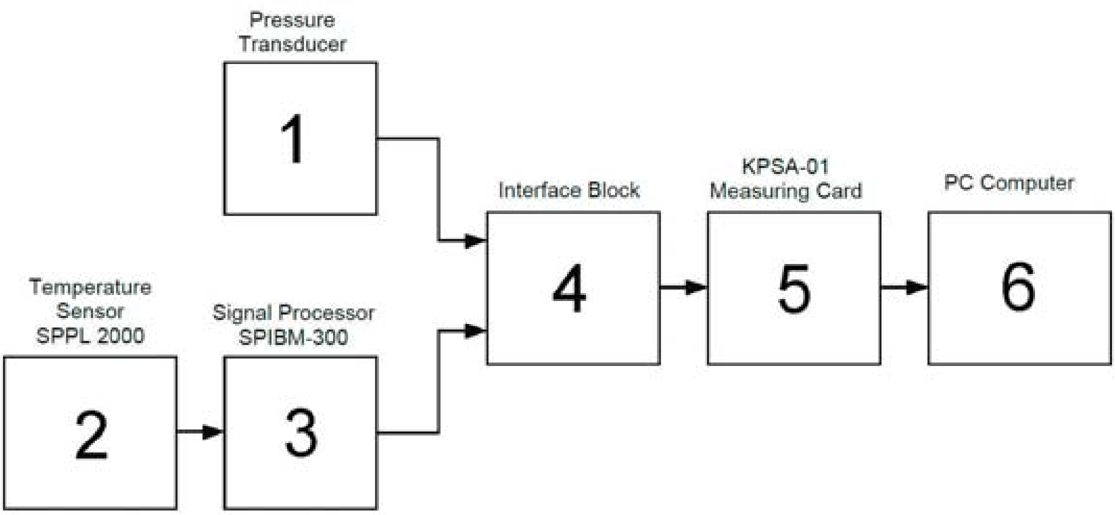

Fig. 5. The block schema of measuring system with the computer data acquisition and recording

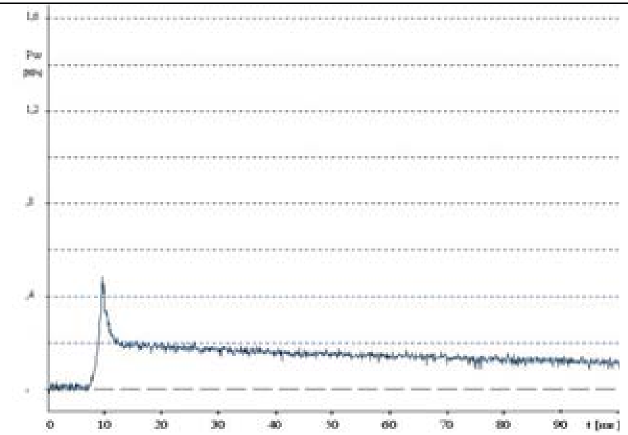

Fig. 6. Exemplary graph of air compression pressure in the combustion chamber of a two-cycle miniature shaftless engine with free piston and minimal tension of the regulating spring

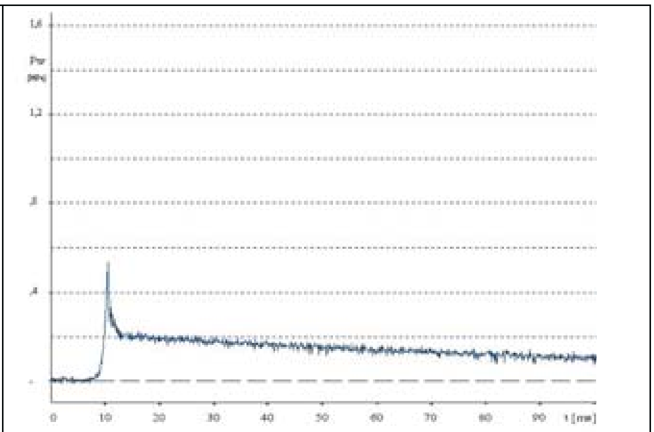

Fig. 7. Exemplary graph of compressed air pressure heated up by glow plug (catalytic igniter) in the combustion chamber of a two-cycle miniature shaftless engine with free piston

The average pressure of compressed air heated up by glow plug (catalytic igniter) was 6.3 bar. Exemplary graph is submitted on Fig. 7.

The aim of investigations of combustion chamber compression pressure in the prototype of a miniature engine with free piston was check what pressure value is required to the mixture ignition. In order to attain this the pressure above piston during the supply of engine by propane with air mixture in the stechiometric composition. The pressure values obtained in these research were contained in the borders from 6.0 to 6.7 bar. The lower results showed on lack of ignition, however the maximum result proved reaching the ignition. Exemplary graph of one work cycle of the prototype engine fueled with propane and air mixture is submitted on Fig. 8.

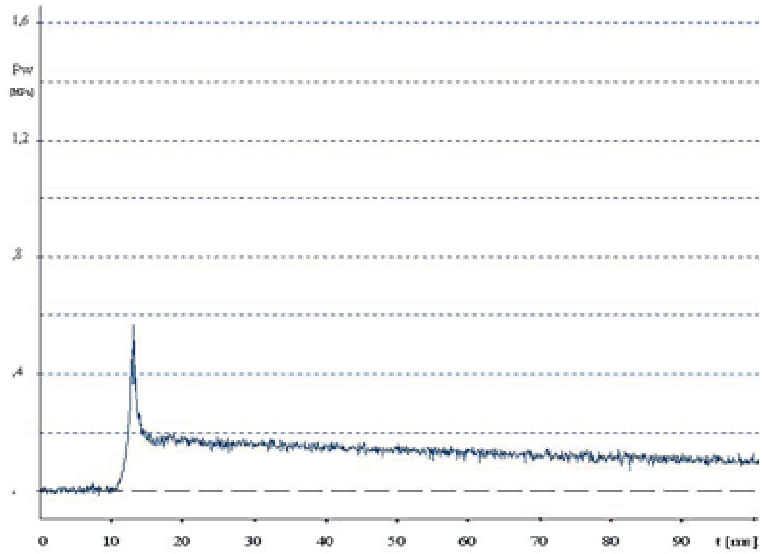

Fig. 8. Exemplary graph of one work cycle of the two-cycle miniature shaftless engine with the free piston

Investigations performed on shaft less mini engine affirmed that the higher compression pressure eases the ignition of gas fuel mixtures. The conclusions resulting from investigation of single compression machine were affirmed simultaneously.

4. Conclusions

1. Exists the large influence of heat transfer to the walls on the charge compression process, like on its combustion.

2. The influence of the material heat transfer and the thickness of the combustion chamber walls is small for the single compression machine, large for the micro engine.
3. The decrease of the combustion pressure values together with raise of the micro chamber area / volume ratio.
4. The dependence of the combustion pressure values from the location place of the catalytic igniter
5. The combustion limit in the small combustion chamber with the large S/V ratio is narrowed and the combustion range is smaller than generally accepted.

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