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RESEARCH OF COMBUSTION SYSTEM WITH SEMI-OPEN COMBUSTION CHAMBER IN A COMMERCIAL SPARK IGNITION ENGINE

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Abstract

During the research of a new combustion system with semi-open combustion chamber for SI engines with use of the rapid compression machine (RCM) and visualisation experimental engine (VEE) it was proved that the application of this system results in shortening of the combustion time, increasing of the maximum cycle pressure and, in effect, increase of the combustion efficiency. The aim of the research using a commercial spark ignition engine was to prove that the similar results (as in RCM and VEE) could be obtained in a wide range of automotive engine operating parameters. In this research the two cylinder, four-stroke air-cooled SI engine, with volume displacement 650 cm³ from Fiat 126 motorcar was used. This engine was fitted with a modified cylinder head and ignition distributor. Two types of prechamber with different shape were installed in different locations into the cylinder head but the ignition distributor had fixed, preadjusted, ignition advance angle in the full range of engine speed. The wide-open throttle characteristics including power, specific fuel consumption and exhaust emission versus engine speed and load characteristics including: specific fuel consumption and exhaust emission versus engine torque were determined for different ignition advance angles. In the lower range of the ignition advance angle the engine showed stable operation at lower speed but unstable at high speed and, inversely, if the ignition advance angle was high the engine operation was stable at the higher speed and unstable at the lower. The engine characteristics during unstable operation were deteriorating. The research results show that improvement of the engine characteristics can be obtained in the full range of operating parameters if the ignition advance angle is varied continuously with the variation of engine speed. The ignition advance angle for the engine fitted with the new combustion system, which was subject of this research, was different form the ignition advance angle for standard engine.

***Keywords**: SI engines, combustion, combustion chamber of piston engines, exhaust emission*

1. Introduction

Despite the fact that the development of internal combustion engines lasts a hundred years, there are still opportunities to improve their performance and constantly new ideas to improve engine operation [1, 3, 4, 5, 7]. In addition, combustion system presented in this publication, designed for spark ignition engines, although it could also be used in diesel engines, brings a new idea to intensify the combustion process in the engine, which should ultimately lead to a reduction in specific fuel consumption and the reduction of toxic exhaust components [9, 10, 11, 12]. The combustion system, which is the subject of research, were divided combustion chamber in the cylinder head a standard petrol engine to the pre-chamber and the main by a partition. Both the pre-chamber and the fundamental are supplied with the same mixture of fuel and air. The mixture contained in the pre-chamber is ignited by the spark plug, and when the differential pressure between the precombustion chamber and the substance, because of combustion in the pre-chamber reaches the desired value to flow out through the opening in the partition, the burning mixture and products of an incomplete combustion chamber substantial [13, 15, 16, 17, 18]. This stream quickly, dynamically moves through the chamber principal, the more rapidly than the combustion velocity of the mixture, causing successive layers of the ignition chamber and a substantial acceleration of the combustion process and consequently to increase the efficiency of combustion. To achieve positive results, the parameters of a new combustion system, which are the volume of pre-chamber, the diameter of the hole in the septum, the location pre-chamber, a place of ignition and ignition timing should be selected so that the flow of the burning of the mixture, there was then, when the piston reaches TDC. Otherwise, as shown by studies using a single compression machine (MPS) and the visualization engine, combustion process is incompatible with the assumptions and effects are small or even negative.

The aim of the study motor was to confirm or negate the test results obtained using MPS engine and visualization. The drawback of studies using the MPS engine and visualization was that they were obtained in a narrow range of engine operating parameters, due to the design constraints of these devices introduced intentionally to improve the optical access to the combustion chamber. In studies using MPS and visualization engine, carried out as far as possible to obtain a range of parameters, the choice of parameters of combustion systems that provide the best results and were chosen solution for the test engine, while it was necessary to take into account the design characteristics of the engine. Due to the relatively simple construction, and the commercial availability of the motor used in this study Fiat 126 with a displacement of 650 cm^3. The studies used two different heads, different shapes and different locations pre-chamber and modernized ignition device, allowing conducting research at a fixed set of ignition timing, the entire speed range of the engine. During the studies, the characteristics of an external high-speed (power, torque, fuel consumption, and the content of toxic components in the exhaust gas as a function of speed) and load characteristics, fuel consumption and toxic fumes as a function of torque. The engine was powered by a stoichiometric mixture or a mixture of depleted $\infty = 1.1$. The results show that it is possible to achieve positive effects throughout the engine operating range as long as you apply variable ignition timing with the change of engine speed. Because at low speeds the engine work well at lower values of ignition timing, but unstable at high speeds. For large values of ignition timing worked stably at high speeds and unstable at low speeds. During the study, better results were obtained when working with a mixture of stoichiometric than lean mixture. In addition, with regard to the configuration of the pre-chamber, one of them cylindrical, placed near the valves, to ensure favourable results, in terms of not only performance but also durability than the pre-chamber arranged opposite to the valve surface of the squeezing.

2. Position and research facility

Due to: relatively simple construction, small size engine, the possibility to carry out a relatively simple design changes and the availability in the market, selected for the type of engine 126A1.076E. It is a two-cylinder, four-stroke, air-cooled engine with spark ignition with the following parameters: cylinder diameter 77 mm, stroke 70 mm displacement 652 cm^3, nominal power of 17.6 kW and torque of 42.5 Nm and maximum speed of 4750 rpm. View of the engine bench shown in Fig. 1 and 2 diagram of the test.

The test stand is equipped with: the eddy current brake E90 Schenck apparatus for measuring torque and rotational speed, which is connected to the cardan shaft of the motor; the installation of the fuel weight measurement of fuel consumption of Pierburg, which uses computer acquisition of measurement results; a special intake system and a special exhaust system, connected to the central system dynamometer; the apparatus for measuring the toxicity of exhaust type K4500 Arcon – Oliver and the type Rosemount 951-Beckman. In the engine exhaust system mounted probe to measure the toxicity of exhaust gases. The intake system is installed special measuring intake and expansion tank for measuring the amount of air drawn in by the engine. Was modernized two cylinder heads, which were to be alternately used in research and the ignition device. Fig. 3 is a view of the head 1 with a cylindrical pre-chamber, which is provided for the intake and exhaust valves. Such a location pre-chamber also required changes to the chamber standard location of the spark plug.

Fig. 1. View of test stand

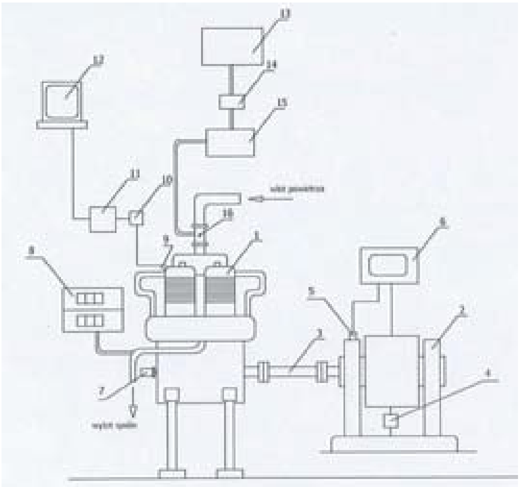

Fig. 2. Schematic of test stand. 1 – tested FIAT 126A engine, 2 – eddy-current brake, 3 – Cardan shaft, 4 – torque sensor, 5 – engine speed sensor, 6 – control unit of eddy-current brake, 7 – crank angle decoder, 8 – exhaust emissions analysers, 9 – pressure transducer, 10 – amplifier, 11 – Indiscope 427, 12 – PC with measurement card, 13 – fuel tank, 14 – fuel filter, 15 – fuel consumption measurement unit, 16 – carburettor and throttle unit

Fig. 3. View of cylinder head with prechamber number 1

Placement at this point the candle made referred to technical difficulties due to the relatively small fins and the wall thickness of the head at this location. It was necessary special seal head.

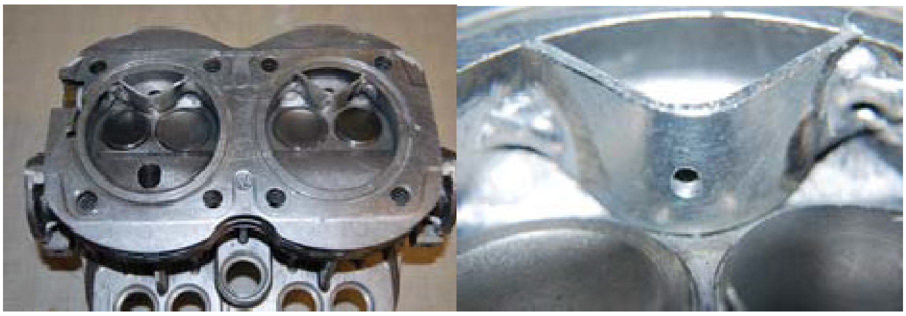

Fig. 4. View of cylinder head with prechamber number 2 before testing

Figure 4 is a view of the head 2 of the pre-chamber which is arranged the at the opposite side with respect to the cylindrical chamber and to better show details of construction enlarged view of the septum and an opening for connecting the pre-chamber chamber constitution. During the study determined external characteristics (torque, power, fuel consumption, exhaust toxicity rotational speed at full throttle) for speed 1500 rpm – 4750 rpm, at 500 rpm, for different values ignition advance angle, ensuring stable operation of the engine, and then determined load characteristics of the engine (fuel consumption and toxicity of exhaust gas as a function of torque at a constant speed), the rotational speed of 2000 rpm, 3000 rpm, 4000 rpm. In the first stage of research was carried out using the head of the precombustion chamber 1 and in the following using the head 2 and the engine is fuelled with a mixture of stoichiometric conditions by variable ignition timing. Then you select a more favourable version of the solution that proved to be head and 1 study was conducted in a wider range of ignition timing and the engine is fuelled with a mixture of stoichiometric and lean.

3. Test results

Figure 5 shows the test results in the form of external characteristics of the engine head 1, a power range and specific fuel consumption at different values of ignition advance angle: 20°, 30°, 40° and 45° CA; Fig. 6 CO, in Fig. 7 HC emissions, in Fig. 8 NOx emissions in terms of external characteristics, with the same values of ignition timing, as for power and specific fuel consumption [2, 6, 8, 14].

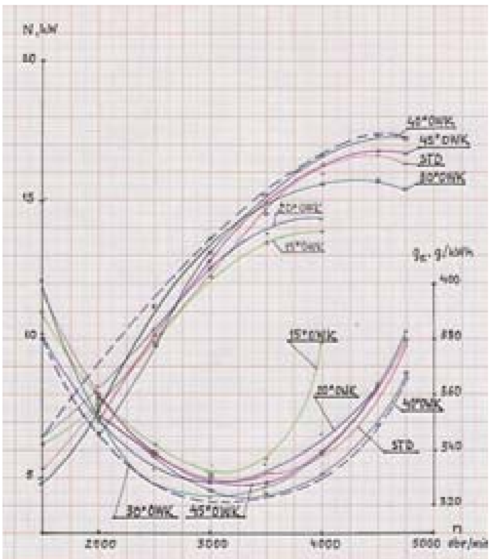

Fig. 5. Power and specific fuel consumption WOT curves for different ignition advance angle for cylinder head number 1

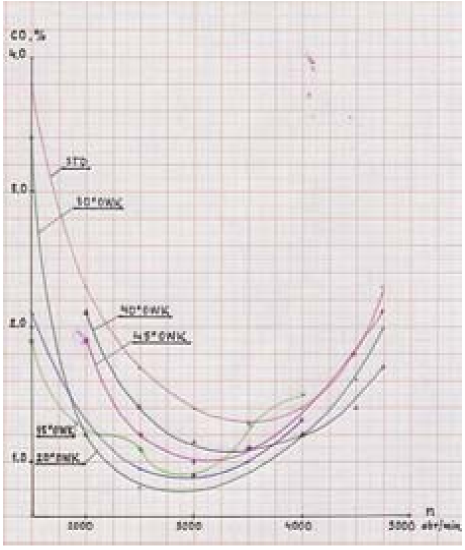

Fig. 6. CO emission WOT curves for different ignition advance angle, for cylinder head number 1

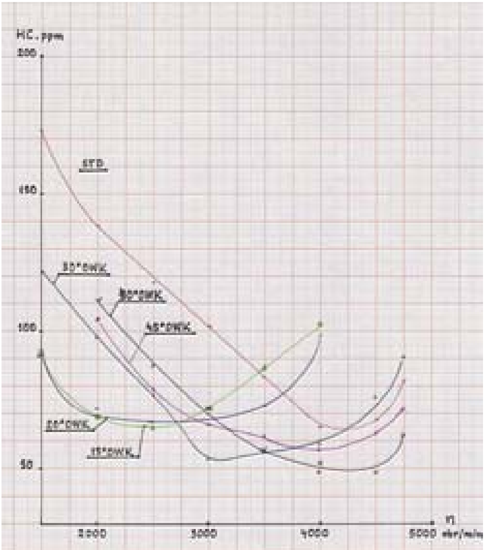

Fig. 7. HC emission WOT curves for different ignition advance angle, for cylinder head number 1

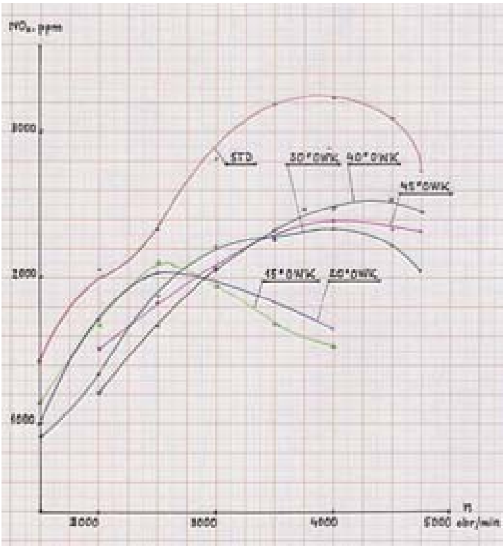

Fig. 8. NOx emission WOT curves for different ignition advance angle, for cylinder head number 1

There is a clear range of beneficial effects for specific values of ignition timing, both in terms of the power unit fuel consumption and toxic emissions. For comparison applied characteristics and test standard motor, which were carried out earlier, before the replacement of the head and the ignition device. The results show that it is possible to achieve positive effects throughout the engine speed range of pre-chamber 1 if with the change of ignition timing will be followed by a change ignition timing. For small values of ignition timing obtained favourable results when the engine is working at low engine speeds. However, when the speed increased, the results have deteriorated at a certain value of the work was very unstable, which was immediately reflected in the very strong growth of hydrocarbon emissions and fuel consumption. Therefore, when the value of the ignition advance angle of 20 deg studies were conducted to the rotational speed of 4000 rev/min. The opposite situation prevailed in the case when the engine worked at high ignition timing. When the ignition timing was 40° CA, the engine worked very unstable at low speeds and, therefore, in this regard determined characteristics from 2000 rev/min. With the increase in speed at the set values ignition timing engine was getting better and obtain more power from the engine standard by approx. 0.8 kW, lower specific fuel consumption and lower toxicity of exhaust gases. Further enhancing the value of the ignition advance angle (45° CA) no longer brought any improvement effects, suggesting that between the ignition timing of 40° CA and 45° CA. It is a limit to enhance the performance of the engine. Mileage characteristics indicate, when compared with the results of using MPS, that in terms of where are achieved positive results, a well-chosen moment is the outflow stream from the pre-chamber to chamber constitution. Thus good results, as in the case of the pre-chamber 1, however, no use of the pre-chamber 2.

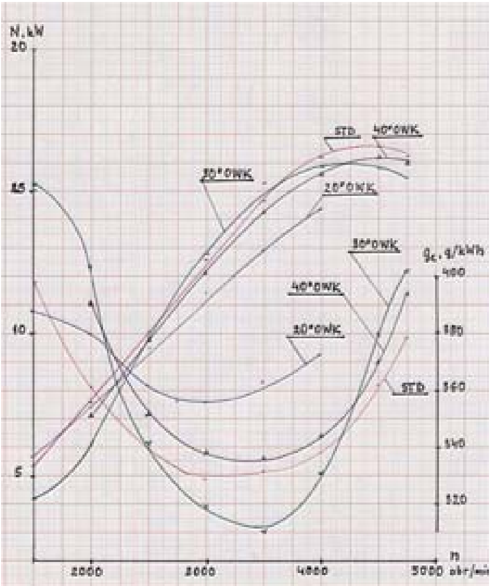

Fig. 9. Power and specific fuel consumption WOT curves for different ignition advance angle for cylinder head number 2

Figure 9 shows the characteristics of the external power range and specific fuel consumption for the head of the prechamber 2, for three values of ignition advance angle: 20°, 30°, 40° CA and for comparison The curves for the standard motor. In the course of these studies, only a certain range of rotational speed of about 2500 rev/min to 4150 rev/min, at an angle of ignition timing of 30° CA, had improved results compared to the standard motor, while the other values of ignition timing results were worse. The problem in these studies was burning a barrier between the pre-chamber and essential. Despite the recovery, partition after a short period of working again underwent damage. Fig. 10 shows the appearance of the head of the chamber 1 and after the test in Fig. 11, the chamber 2 after the tests. In the case of the head of the cylindrical precombustion chamber, there has been no damage to the head, and the piston head showing the shape of the reflected cylindrical chamber, which does not mean, however damage to the piston but is caused by the transfer of particulate barrier on the piston head and the deposition on the surface.

Although it has long been conducting studies with the head of the chamber 1 there are no problems of stability However, if the head of the pre-chamber 2 was burn-out the baffle in place, wherein a hole for the outflow stream of the burning mixture from the pre-chamber chamber constitution. Burn partition must have a negative effect on the combustion process in the engine and on the conditions of flow of the combustion chamber. Ignited in the antechamber combination could not produce light of appropriate energy able to move throughout the combustion chamber essential. The outflow stream occur in a random manner, and therefore not able to ensure good results with respect to speed up the combustion process. Certainly, deterioration flow conditions affected the increase in specific fuel consumption and exhaust emissions.

Fig. 10 View of cylinder head with prechamber number 1 after testing

Fig. 11. View of cylinder head with prechamber number 2 after testing

Regarding the results of an engine with pre-chamber 1, the engine is fuelled lean mixture, the obtained results are also worse than when running the engine with a stoichiometric mixture. First, there was a very large spread of results from research in specific fuel consumption and exhaust emissions.

4. Conclusions

1. The results of the production of engine combustion system of the divided combustion chamber show that with suitable selection of system performance can be improved engine performance relative to the performance of a standard motor, with respect to power specific fuel consumption and exhaust emissions.
2. To improve engine performance, split the combustion chamber for all of its work, it is necessary to control the spark advance angle as a function of engine speed; with an increase in engine, speed should grow ignition timing.
3. In the case of small values of ignition timing engine gave better results at low speeds, while he worked unstable at high speeds; for large values of ignition timing engine worked unstable at low speeds, and provide favourable results when working at high speeds.
4. Comparison of test results using two different configurations of pre-combustion chamber, indicating that much better results were obtained in the pre-chamber cylinder arranged in the vicinity of the intake and exhaust valves, spark plug electrodes placed near a wall of the combustion chamber, which can be associated with a significantly favourable conditions of heat exchange.
5. Tests engine production, the combustion system of the divided combustion chamber, fed with lean mixture, revealed that favourable results were obtained at higher than the ignition timing for the engine-powered stoichiometric mixture, which is due to a lower combustion speed of the mixture.

6. As a result of research carried out on the engine production were confirmed by the test results obtained using a single machine compression and visualization engine, when it comes to the possibility of obtaining the effects of using a new combustion system.

References

[1] Glinka, W, Leżański, T., Wolański, P., *Zastosowanie fotografii szybkiej do badań spalania w silnikach SI z półotwartą komorą wstępną*, Journal of KONES, Vol. 14, 2007.

[2] Haller, P., Jankowski, A., Kolanek, C., Walkowiak, W., *Microemulsions as fuel for diesel engine*, Journal of KONES, Vol. 19, No. 3, pp. 165-170, 2012.

[3] Heywood, J. B., *Internal Combustion Engine Fundamentals*, McGraw-Hill, New York 1988.

[4] Jankowski, A., *Chosen Problems of Combustion Processes of Advanced Combustion Engine*, Journal of KONES, Vol. 20, No. 3, DOI: 10.5604/12314005.1136852, pp. 203-208, 2013.

[5] Jankowski, A., *Influence of chosen parameters of water fuel microemulsion on combustion processes, emission level of nitrogen oxides and fuel consumption of ci engine*; Journal of KONES, Vol. 18, No. 4 2011.

[6] Jankowski, A., Kowalski, M., *Environmental Pollution Caused by a Direct Injection Engine,* Journal of KONES, Vol. 22, No. 3, DOI: 10.5604/12314005.1168461, pp. 133-138, 2015.

[7] Jankowski, A., *Modelling of Combustion Processes of Liquid Fuels,* Journal of KONES 2012, Powertrain and Transport, Vol. 19, No 4, pp. 239-244, Warsaw 2012.

[8] Jankowski, A., Sandel, A., Jankowska-Siemińska, B. Sęczyk, J. *Measurement of drop size distribution in fuel sprays by laser methods,* Journal of KONES Vol. 8 No. 3-4, pp. 334-345, 2001.

[9] Jankowski, A., Sandel, A., Seczyk, J., Jankowska-Sieminska, B., *Some problems of improvement of fuel efficiency and emissions in internal combustion engines*, Journal of KONES, Vol. 9, No. 3-4, pp. 333-356, 2002.

[10] Jankowski, A., *Study of the influence of different factors on combustion processes (Part one),* Journal of KONES, Vol. 16, No. 1, pp. 209-216, 2009.

[11] Jankowski, A., *Study of the influence of different factors on combustion processes (Part two),* Journal of KONES 2009, Vo. 16, No. 3 pp. 135-140, 2009.

[12] Jankowski, A., *Test Stand for Modelling of Combustion Processes of Liquid Fuels,* Journal of KONES, Vol. 21, No. 2, DOI: 10.5604/12314005.1133885, pp. 121-126, 2015.

[13] Jankowski, A., *Test Stand for Modelling of Combustion Processes of Liquid Fuels,* Journal of KONES, Vol. 21, No. 2, DOI: 10.5604/12314005.1133885, pp. 121-126, 2015.

[14] Leżański, T., *Badania silnika o zapłonie iskrowym wyposażonego w nowy system spalania z półotwartą komorą spalania*, Sprawozdanie merytoryczne z realizacji projektu badawczego Nr 4T12D 029 30, Warszawa 2009.

[15] Leżański, T., Rychter, T., Teodorczyk, A., *Prechamber combustion system studies using rapid compression machine*, Journal of KONES International Combustion Engines, Vol. 7, No. 1-2, Warsaw-Lublin 2000.

[16] Zurek, J., Jankowski, A., *Experimental and Numerical Modelling of Combustion Process of Liquid Fuels Under Laminar Conditions,* Journal of KONES, Vol. 22, No. 3, DOI: 10.5604/12314005.1134559, pp. 309-316, 2015.

[17] Zurek, J., Jankowski, A., *Experimental and Numerical Modelling of Combustion Process of Liquid Fuels Under Laminar Conditions,* Journal of KONES, Vol. 22, No. 3, DOI: 10.5604/12314005.1134559, pp. 309-316, 2015.

[18] Zurek, J., Kowalski, M., Jankowski, A., *Modelling of Combustion Process of Liquid Fuels under Turbulent Conditions,* Journal of KONES, Vol. 22, No. 4, DOI: 10.5604/12314005.1168562, pp. 355-344, 2015.