**ISSN:** 1231-4005
**e-ISSN:** 2354-0133
**DOI:** 10.5604/12314005.1168470

# INFLUENCE OF COMPRESSION RATIO ON COMBUSTION, TURBULENCE, SWIRLS INTO MODEL COMBUSTION CHAMBER OF SI ENGINES

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***Abstract***

*The results of the visualization researches, with the pressure measurement results are presented in the paper. Researches deal with the combustion system with semi-open combustion chamber for spark ignition engines. This system was elaborated in Aircraft Engine Department of Heat Engineering Institute of Warsaw University of Technology. During researches the influence of CR on a flame front propagation and turbulences into combustion chamber, when CR and ignition advance are varied, was determined. The model combustion chamber was made with the constant volumes ratio (the prechamber volume to the prechamber plus main combustion chamber volumes) of 28%. The CR were varied: 6:1, 8:1, 10:1 and 12:1, by changing of combustion chamber length and establish high. The researches were performed using rapid compression machine (RCM). The combustion sequences were recorded using high-speed digital camera with speed of 5000 frames per second. Simultaneously with combustion sequences recording, the high-speed pressure courses were registered. The research results show that the growth of compression ratio causes an improvement of combustion system performances; an increase of maximum cycle pressure and useful work field. The improvement of the performances is caused mainly by shortening of the combustion time and intensification of the turbulences and approaching of supposed combustion course.*

***Keywords***: *internal combustion engines, spark ignition, combustion processes, new combustion systems, combustion process visualisation*

## 1. Introduction

Researches presented in this paper concern the combustion system with semi-open combustion chamber for spark ignition engines [1, 2, 3]. This system was elaborated in Aircraft Engine Department of Heat Engineering Institute of Warsaw University of Technology. The researches concern the determination of influence CR on a flame front propagation and turbulences into combustion chamber when CR and ignition advance angle (IAA) are varied.

Operation of this system is based on comprehensive analysis of existing combustion system internal combustion engines, and multi interdisciplinary knowledge in such domain as thermodynamics, combustion physics and chemistry, fluid flows, heat transfer, computer sciences, materials, etc. The key role in the combustion system operation plays a turbulence. To take possession of high-speed visualization equipment enables proving how the turbulence influences on combustion process. Direct flame photographs show a structure and development of the jet stream, and flame front displacement [4, 5, 6, 7, 8].

The ideal cycle analysis showed that indicated fuel conversion efficiency increased continuously with the compression ratio (CR). However, other processes, which influence on engine performance and efficiency, vary with changes CR, for example, combustion rate and stability, turbulences, heat transfer, friction and another. Moreover, the ability to increase of the CR is limited by the octane quality of fuels and knock. In the combustion system with semi-open combustion chamber, the growth of CR is additionally limited by combustion mechanism, because this combustion mechanism in the combustion system with semi-open combustion chamber is strongly depended on the ignition advance angle and a stream (jet) range out flowing from prechamber to main combustion chamber through the orifice hole in the partition. Other combustion system parameters have smaller influence on combustion system performances [10, 11, 12, 13 14] Therefore, it is the most important to recognize what is mechanism of flame front propagation in the combustion system with semi-open combustion chamber for different CR. Therefore, to realize these researches the test stand, measurement equipment and model combustion chambers have been prepared. The model combustion chamber make with the constant volumes ratio of the prechamber volume to the prechamber plus main combustion chamber volumes, of 28%, but the CR were varied: 6:1, 8:1, 10:1 and 12:1, by changing of combustion chamber length and establish height. The researches were performed using rapid compression machine (RCM) [15, 16, 17, 18]. The combustion sequences were recorded using high-speed digital camera with speed of 5000 frames per second. Simultaneously with combustion sequences recording, the high-speed pressure measurements were registered. Apply these results the combustion course with pressure course curve were compared. If the length of combustion chamber was smaller, the burning time in combustion chamber was shorter but pressure results increased. The strong swirls were observed on the edges of combustion chamber. They have apparently influence on the combustion mechanism, because they brake the propagation of stream outflowing to main combustion chamber from the orifice hole in the partition [18, 19, 21]

## 2. Experimental apparatus

Figures 1 and 2 show the test stand schematic and the test stand view, respectively. Application of the RCM allows obtaining of high-speed combustion photographs at very good quality, in the plain goes over the longitudinal axis of the combustion chamber. Moreover, it does independent of research results from disturbance caused by cyclic induction and exhaust processes. The details of the research apparatus can be find in references [20, 22]

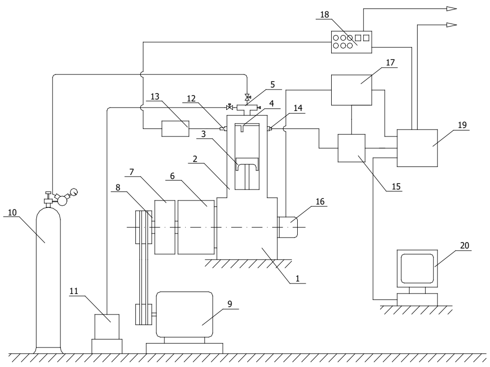


*Fig. 1. Schematic of RCM test stand. 1. Crank mechanism, 2. Combustion chamber, 3. Piston, 4. Insert model combustion chamber 5. Refuelling and emptying system, 6. Electromagnetic clutch 7. Flywheel, 8. External belt transmission 9. Electric motor, 10. Pressurized bottle 11. Vacuum pump, 12. Spark plug, 13. Ignition apparatus, 14. Piezoelectric transducer 15. Amplifier, 16.Crank encoder 17. Indiskope 427, 18. ECU of optical system 19.Measurement card, 20.PC*

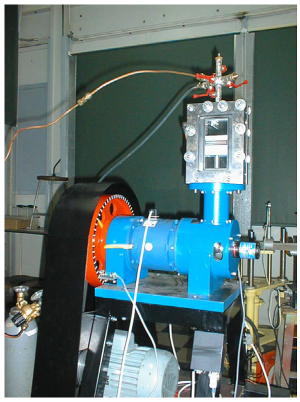

*Fig. 2. View of test stand*

The RCM includes crankshaft, connecting rod, sliding rod, piston and combustion chamber. Cross section of the piston is rectangular, but combustion chamber is parallelepiped.

Figure 3 shows optical system applied in the research. This system includes plain and concave mirrors, lenses, optical knife, source of light and electronic digital camera, Photram SA 1.1. In optical system parallel luminous flux, which illuminates the research volume, was shaped. The light source was the light emitting laser diode.

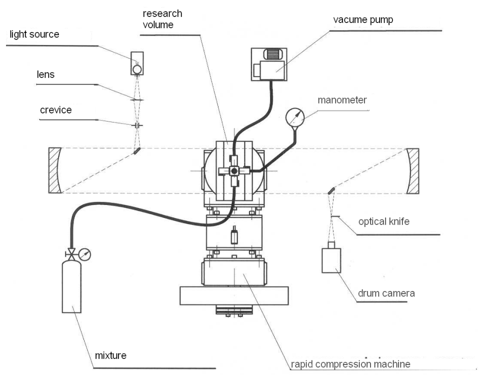


*Fig. 3. Schematic of the optical system*

*Fig. 4. View of combustion chamber models before testing*

The images were registered in big computer memory with frequency– 5000 frames per second, exposition time 50 μs.

## 3. Research results

### 3.1. Research objects

The research objects were the model combustion chambers, in which the constant ratio of a prechamber volume to amount of prechamber and main combustion chamber volumes was set: 28 percent. Therefore, the prechamber volume is expressed in percent. The compression ratio (CR) was varied from 6:1, through 8:1 and 10:1 to 12:1. The height of combustion chamber was set, but the length of main combustion chamber was varied. Figure 4 presents the view of the model combustion chamber, which were fixed in cylinder head of rapid compression machine (RCM). During testing of the model combustion chambers, the ignition timing (ignition advanced angle) was changed from $20^0$ CABTDC to $70^0$ CABTDC, to determine the intensive stream outflow of burning mixture and radicals, from prechamber to main combustion chamber, through the orifice hole in partition, when piston is at TDC. The mixture ignition was initiated in the prechamber. The orifice hole diameter was 3 mm. The orifice diameter, the prechamber volume, the ignition place and the ignition timing are the most important parameters of combustion system with semi-open combustion chamber. They decide about the combustion mechanism in this system and the performances of the system.

### 3.2. Flame front propagation in combustion chamber

During the tests, the photographs of the combustion courses were filmed, using an electronic high-speed camera and the high-speed pressure courses were recorded. The combustion courses for different CR will be presented on the selected examples. They make possible to estimate how the CR influences on the combustion process, turbulences, maximum cycle pressure, and other system performances. The presented photographs and pressure curves concern the results, which were obtained for the best of ignition timing, for determined of CR, when the maximum pressures were achieved. It is necessary to stress, that in the combustion system with semi-open combustion chamber it is required to obtain the start of the stream outflow of burning mixture and radicals, from prechamber to main combustion chamber, when the piston is at TDC, and stream energy was enough to propagate all main combustion chamber before the clearance between piston crown and partition appears. This is very difficult to achieve, especially in automotive engines in which the loads and speeds are very frequently varied.

Figure 5 shows the course of combustion and turbulences in the combustion chamber with CR 6:1 and ignition timing $30^0$ CABTDC. The outflow from prechamber to main combustion chamber starts, when the piston passed the TDC (0.0272 s), in spite of the stream outflowed from orifice hole in partition quickly propagated across the main combustion chamber. Initially, combustion process was too slow, to equalize a pressure decrease caused by expansion process. This can see in high-speed pressure curve as a decrease of pressure after TDC (Fig. 6). After the time about 0.8 ms from the prechamber outflow start, the pressure begins to increase. The maximum pressure value was little bigger than the compression pressure, that is 0.913 MPa and 0.747 MPa, but it was gone away TDC, and therefore the work field was big for this cycle. The IAA is too small.

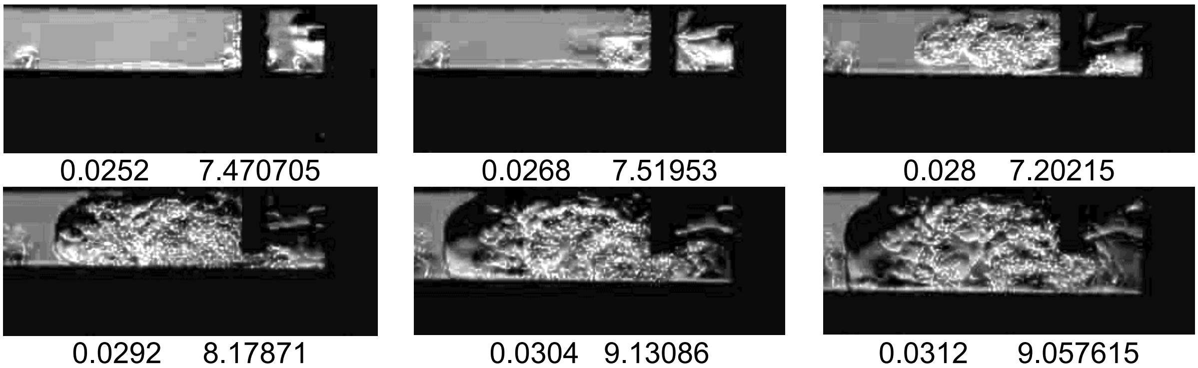


*Fig. 5. Combustion process development in combustion chamber model: Vp=28%, CR 6:1; IT=30$^0$ CABTDC*

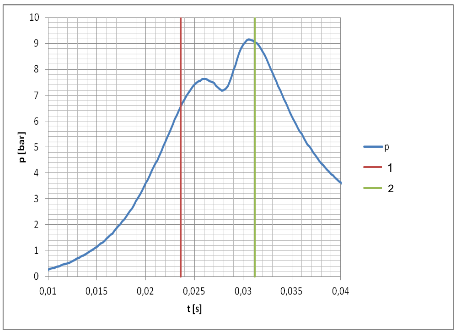


*Fig. 6. High-speed waveforms of pressure in combustion chamber as a function of burning time: CR: 6:1, IT=30$^0$ CABTDC*

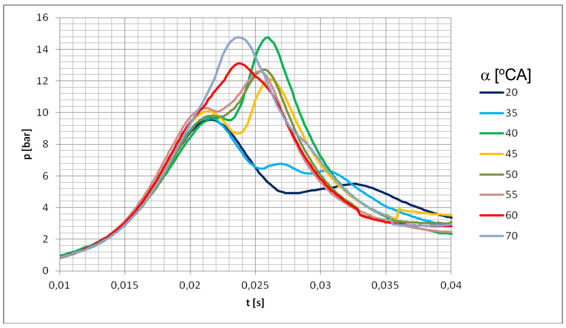


*Fig. 8. High-speed waveforms of pressure in combustion chamber as a function of burning time: CR= 8:1; IT= 20$^0$ to 70$^0$ BTDC*

Figure 7 shows the course of combustion development in the combustion chamber with CR 8:1, and ignition timing 40$^0$ CABTDC. The outflow from prechamber to main combustion chamber starts when the piston was at TDC (0.0222 s). This stream high tubulised with flame front quickly propagates across the main combustion chamber, and after the time of 1.6 ms, it achieves opposite wall of main combustion chamber, before the clearance between the piston crown and partition appears.

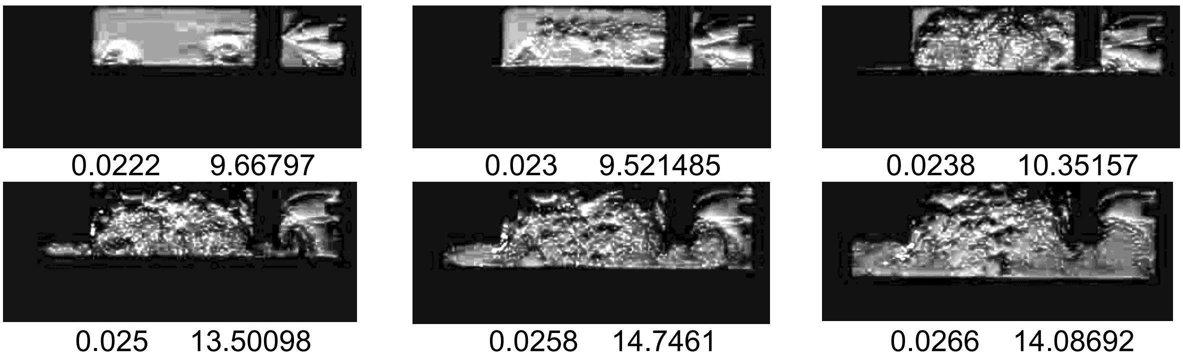


*Fig. 7. Combustion process development in combustion chamber model: Vp=28%, CR= 8:1; IT=40$^0$ CABTDC*

When the clearance was opened, the riversides flow from main combustion chamber to prechamber began, because the pressure in main combustion chamber is higher than in prechamber. Moreover, the intensive mixing of the charge in all space of combustion chamber and continuous pressure growth are observed. The high maximum pressure, of 1.475 MPa is obtained in the time about 3.6 ms from the moment of outflow from prechamber (Fig. 8). In the movies, photographs the intensive flows, highly tubulised charge between prechamber and main combustion chamber and numerous streams outflowed from different crevices of combustion chamber can see. Figure 8 presents the high-speed pressure curves for the ignition timing from $20^0$ to $70^0$ CABTDC. The reason from these curves it is too estimate influence of ignition timing on the maximum pressure value and the useful work filed. The values are similar for the ignition timing $40^0$ and $70^0$ CABTDC, but for bigger IAA the compression field is higher, because a burning mixture is compressed instead of the fresh mixture. In the photographs of combustion course it can be seen, that decrease of the main combustion chamber length was profitable for the combustion mechanism realization, and high turbulisation, because the high speed useful field and high maximum pressure cycle were obtained.

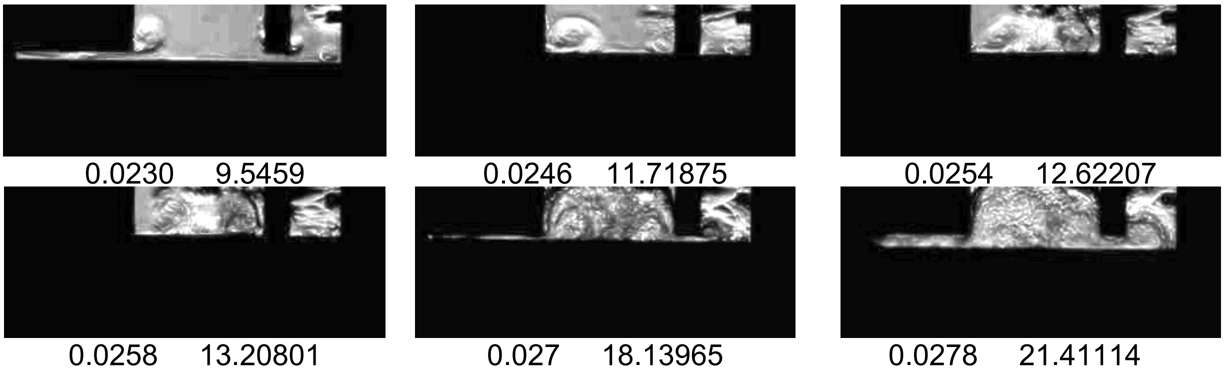


*Fig. 9. Combustion process development in combustion chamber model: Vp=28%, CR= 10:1; IT=$40^0$ CABTDC*

Figure 9 presents the course of combustion development in combustion chamber with CR 10:1 and ignition timing $40^0$ CABTDC. The length of main combustion chamber is smaller than former and is 9.4 mm. In the photographs during compression stroke very strong swirls formation can be seen at all sharp edges of combustion chamber and especially on the left side of combustion chamber. Above the piston crown, a surface layer is created. When the piston comes to the TDC, the swirls are stronger and stronger. The outflow from prechamber to main combustion chamber starts when the piston was at TDC (0.025 s), but the vortex was so strong, that the stream outflowed from orifice hole was pushed up to higher surface of combustion chamber. This stream not till when was at the wave crest it was drawn in the middle of the vortex. In effect, the speed of mixing increased and the stream quickly achieves the opposite wall of main combustion chamber. The stream achieved the opposite wall, before the clearance between piston crown and partition was opened. When the clearance appears the burn up process of the charge and intensive mixing begins. The flows between prechamber and main combustion chamber, and jet stream from different crevices were profitable for this process.

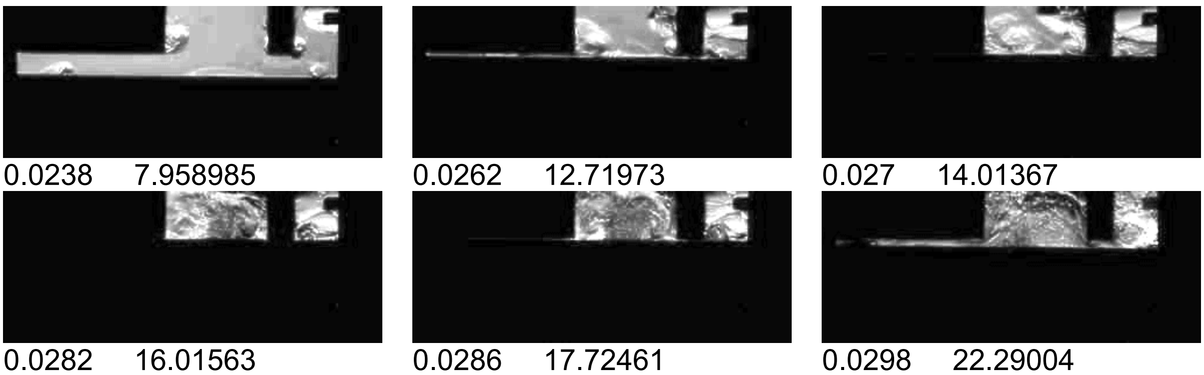


*Fig. 10. Combustion process development in combustion chamber model: Vp=28%, CR=12:1; IT=$50^0$ CABTDC*

Figure 10 shows the course of combustion development in combustion chamber with CR 12:1 and ignition timing $50^0$ CABTDC. The length of combustion chamber was 25 mm, whereas the longest of main combustion chamber had 56 mm. The course of combustion was very similarly as for CR 10:1. The very strong swirl during compression stroke especially on the left side of main combustion chamber can see. The outflow from prechamber to main combustion chamber begins before TDC of the piston (0.0262 s). However, directly after closing of the clearance between piston crown and partition, the stream achieves the opposite wall of main combustion chamber (0.027 s). Owing to the intensive mixing of burned and not burned mixtures the combustion in the main combustion chamber is initiated. At the time 0.0298 s, the maximum cycle pressure – 2.23 MPa was achieved.

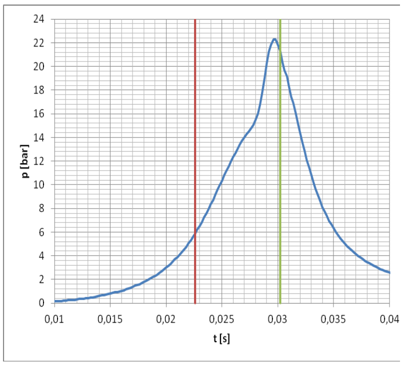


*Fig. 11. High-speed waveforms of pressure in combustion chamber as a function of burning time: CR= 12:1; IT=$50^0$ CABTDC*

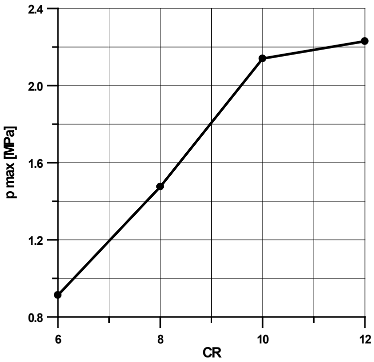


*Fig. 12. Influence of compression ratio (CR) on the cycle maximum*

Figure 11 shows the history of high-speed pressure for the ignition timing of $50^0$ CABTDC and for compression and expansion. Figure 12 shows dependence between maximum pressure value and compression ratio, for the most profitable values of ignition timing for each CR. The length of the main combustion chamber was varied but their height was constant, when changing CR. The growth of CR causes substantial increase of maximum cycle pressure.

## 4. Conclusions

1. The principal problem of combustion system operation with semi-open combustion chamber consists in to assure that jet-stream outflow from prechamber to main combustion chamber begins when the piston is at TDC, and the jet-stream will be have a sufficient energy to displace quickly all combustion chamber, before the clearance between piston crown and partition appears.
2. The combustion system with semi-open combustion chamber enables the improvement of engine performances: engine efficiency, repeatability of ignition, reliability improvement, exhaust emissions decreasing if the combustion systems parameters will be well matched.
3. The research results show that the growth of compression ratio caused an improvement of combustion system performances; an increase of maximum cycle pressure and combustion efficiency (useful work field).
4. The improvement of the performances is caused mainly by shortening of the combustion chamber length, intensification turbulences, and earlier approaching of supposed combustion course.
5. The increment of maximum cycle pressure values was bigger when compression ratio growths at smaller compression range; growth of compression ratio from 6:1 to 10:1 causes growth of maximum pressure about 2.3 time, but from 10:1 to 12:1 only 4.2 percent.
6. Visualisation of combustion process showed that in the sharp edges of combustion chamber the strong swirls are formed.

7. The growth of CR causes increase of turbulences and swirls, which had a big influence on combustion development.
8. During researches, the knocking tendency up to 12:1 was not observed.

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