SPARK PLUG WITH THE INCREASED ENERGY FOR CREATING OF INITIAL COMBUSTION CENTRE

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Abstract

Variability of the working cycle of the internal combustion engines with the combustion of homogenous mixture is a long-term problem of SI engines. The paper shows a decrease of cycle variability and an increase of the engine efficiency by using a spark plug, whose design allows the ignition of the mixture in the same way as using a classical spark plug by the high-voltage discharge between electrodes of the spark plug and at the same time increases the energy for the development of mixture combustion in the initial phase by a flame jet from a very small ignition chamber. Energy of flame jet for the mixture ignition into compression volume at engine cylinder is fully 100 times higher to energy of high-voltage discharge on the spark plug. The laboratory results of experimental works on vehicle SI engine (the visual inspection of initial phase of burning, course of cylinder pressure, engine power data) are showed. On basis performed tests has been projected the new design of the spark plug with the integrated combustion chamber. According to our engineering design was made the new spark plug with the ignition chamber like functional samples in company BRISK. Proving test with this new spark plug was performed on two different test engines at Department research laboratory on Technical University of Liberec. The experiments confirm the await results: the engine characteristics has been significantly improved. New design of spark plug with integrated chamber he was enregistered at Bureau of industrial ownership at Prague.

Keywords: *Ignition of mixture, Variability of working cycles, Spark plug, Ignition chamber*

1. Introduction

The initiation of the combustion process in the spark ignition (SI) engines is effected by the mechanism of high temperature ignition of a very small volume of the prepared mixture. By a high-voltage discharge on the electrodes of the spark plug, the temperature in the very small volume of the combustible.

The produced hydrogen peroxides (ROOH) and peroxides (ROOR) decompose quickly, producing the energetically rich activated particles - free radicals, which initiate the course of subsequent chain reactions, accompanied by the release of a large amount of heat:

$$ROOH \rightarrow RO^{\bullet} + {}^{\bullet}OH.$$

After a sufficient concentration of activated particles is achieved, the whole process culminates with the formation of a centre of ignition. From the centre of ignition, the burning is propagated by the effect of the transfer of heat and a gradual increase of concentration of the products of pre-oxidation reactions in the area preceding closely the zone of burning in the centre of the ignition. The concentration of the activated particles in the mixture that has not been combusted yet increases due to the thermal effect (conduction of heat) from the front of the flame. At the same time, activated particles from the zone of burning are brought to the not yet combusted mixture as well. In this way, suitable conditions are created for the propagation of the flame into the surrounding mixture. The advance of the flame until the mixture in the whole combustion chamber (the cylinder of the engine) is burnt completely, is provided with the propagation and development of oxidation reactions first from the centre of the ignition and afterwards, from other areas where the mixture is already being burnt, too.

The SI engines (using petrol or gas) employ an external formation of the mixture in their majority; consequently, the mixture is brought to the cylinders of the engine in a very high degree of preparation: for the final formation and homogenisation of the mixture in the cylinder of the engine (in case of petrol, also for its subsequent complete evaporation and mixing of the fuel vapours with air) there is available a relatively long period, including the whole filling stroke and a considerable part of the compression stroke, too.

However, the kinetic combustion of the prepared homogeneous mixture and the apparently unequivocal conditions for its ignition and its subsequent burning are complicated in practice by a number of factors that bring about a poor reproducibility of the operating cycles resulting in a high variability of working cycle (called like inter-cycle variability also). This variability complicates the optimisation of the adjustment of the SI engine, and it impairs its energetic parameters (i.e., those of its total efficiency), as well as its performance and emission ones.

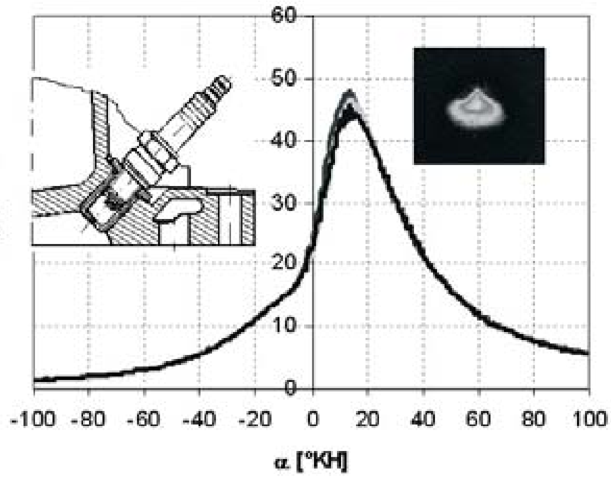
The variability of working cycle is determined both by the ratio of the standard deviation of the mean indicated pressure to the average value of the mean indicated pressure into working cycle and by the ratio of the standard deviation of the maximum pressure to the average value of the maximum pressure into working cycle in the operating regime (for evaluation of variability is need the dates from more working cycles, approximately 150).

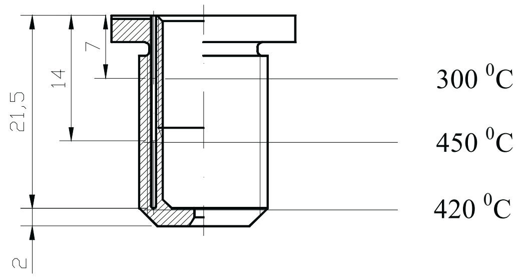
A high inter-cycle variability of the SI engines is characteristic for the start of the combustion, until 5% of the fuel is combusted. This fact is explained by the variability of certain factors in the centre of the ignition and its close vicinity (the effect of the turbulent whirling, local lacks of homogeneity due to residual gases); however and without any doubt, an important influence is exerted by a low and at the same time, variable energy of the high-voltage discharge, too. The movement of the filling (the mixture) in the close vicinity of the spark gap influences upon the concentration of the products of the pre-oxidation reactions and upon the ionisation of the mixture in the course of the high-voltage discharge (in the centre of ignition under formation). The changes in the composition of the ignited mixture in the surrounding of the centre of ignition are notable as well, due to the effect of the combustion waste left over from the preceding cycle. A certain improvement in the initial phase of burning, i.e. for the ignition, can be achieved by increasing the energy used in the high-voltage discharge (e.g. on the petrol engines, the energy of the high-voltage discharge is of 10 mJ approximately, with larger gas fuelled engines, it amounts up to 120 mJ) - however, there is always one centre of ignition only. Although in the turbulent scene of the compression volume the secondary centres of ignition are produced due to the turbulent diffusion of the burning elements into the not yet combusted mixture, and their number determinates the overall character of the burning process. However, the casual nature of these phenomena and a relatively low number of the additional centres of ignition cannot provide for a sufficient reproducibility (stability) of the operating cycles.

The concept of the ignition of the mixture in the combustion space by supporting the development of the centre of ignition in an protected volume around electrodes of the spark plug, with subsequent fast advance of the front of the flame into the compression space in the cylinder, has been given attention in the Department of vehicles and engines of the Technical University of Liberec. There has been tested an adapted spark plug with a very small ignition chamber around electrodes of the spark plug ignition - the mixture in the cylinder is subsequently ignited by the outflow of the burning mixture from the ignition chamber to the main compression volume in engine cylinder (energy content of flame jet is at the least 1 J). The experimental research was performed on the petrol engine (naturally aspirated both petrol and gas engine for car, $\lambda = 1$).

2. Results of research program

The example from the experimental research of prepared mixture ignition by spark plug with the combustion chamber show the Fig. 1 till Fig. 3: on p-α diagram of SI gasoline engine is clearly see the expressive decrease of working cycle variability (on diagram there are the course of cylinder pressure with the minimum, mean and maximum value p_i from collection of 150 working cycle). The embedded pictures then reflect the design of ignition system with ignition chamber and the flame jet of the burning mixtures from ignition chamber to compression volume in engine cylinder.





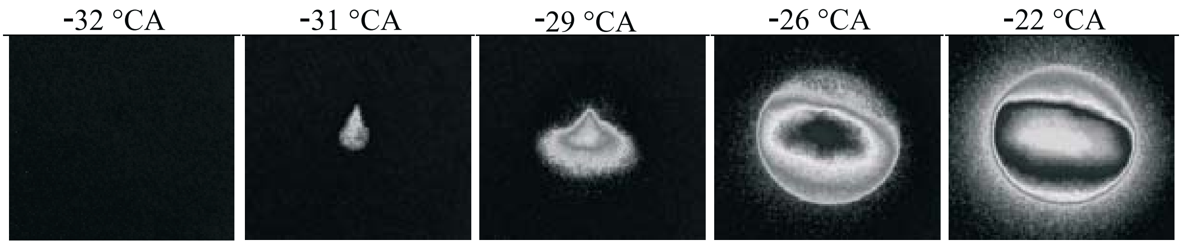


Fig. 1. The ignition system with the combustion chamber was designed like the assembly from the classical spark plug and the chamber body with a certain protected inner volumes below classical spark plug. Protected volume of combustion chamber is interconnected by one or several holes with the compression space in engine cylinder. On Fig. 1 is the chamber with only one hole in the centre of the chamber bottom wall. On this chamber was metering the temperature in wall using of jacketed mikrotermocouple (diametr of the jacked 0.25 mm) - the writed value of temperature was measured on regime n = 4000 RPM and p_e = 0.75 MPa. The visualization (AVL Visioscope) of the initial phase of burning shows the fast development of the burning after burst of burning mixture from the chamber

Performed metering however showed also on problems, which were on the using way of chamber ignition (i. e. chamber ignition system with the inlet of combustible mixtures to the chamber by one or several holes on the chamber bottom from the cylinder volume during compression stroke). On idling and on very low load has had test engine worse characteristics (increasing variability of the mean indicated pressure p_i and maximum pressure p_{max} too) than on ignition by classical spark plug. After experiment with several design variant of chamber ignition and analysis of design possibilities for optimizing of chamber ignition configuration was designed solution with the extension of the central electrode to the hole at bottom wall of chamber (see Fig. 4.), that have support contemporary ignition mixtures inside of combustion chamber and in compression space in the cylinder engine.

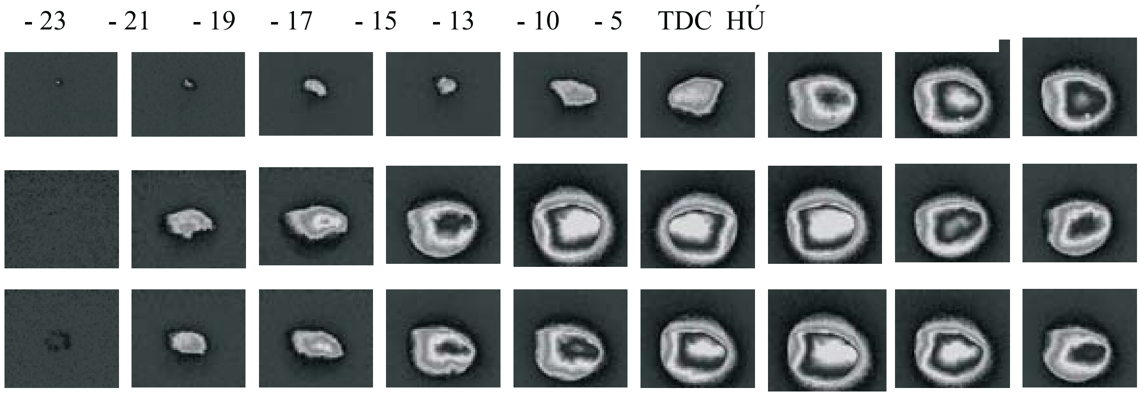


Fig. 2. The effect of the chamber ignition on the initial phase development. Upper series is with the classical spark plug. Second series is visualization record with the mixture ignition at engine cylinder by the chamber ignition with 1 central hole and 3 holes on periphery on chamber bottom wall. Third series is for mixture ignition at engine cylinder by the chamber ignition with 1 central hole and 10 holes in the middle of chamber bottom wall area

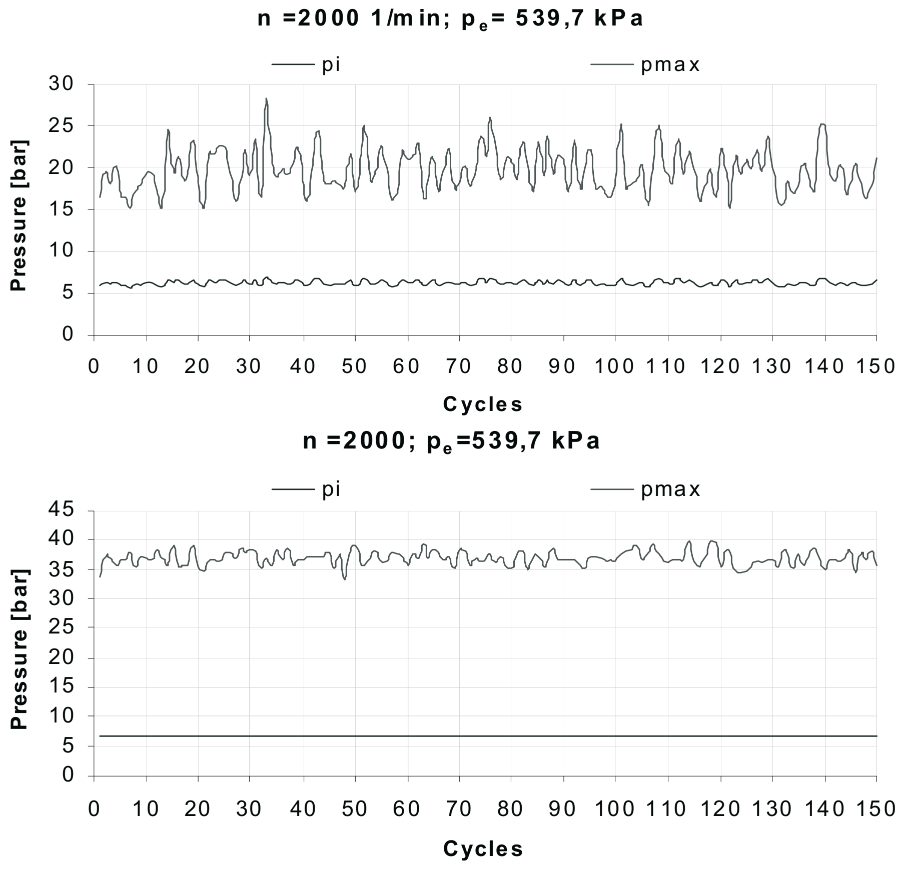


Fig. 3. The comparison of the mean indicated pressure variability p_i and the maximum pressure variability p_{max} at collection of 150 working engine cycle: upper graph is for ignition of mixtures by the classical spark plug, lower graph is for ignition mixtures using the combustion chamber

Selected results from metering on test engine at Department research laboratory on Technical University of Liberec show the graphs on Fig. 5 till Fig. 8.

Optimization research works on SI engine with chamber ignition using spark plug with the extension of the central electrode to the hole at bottom of chamber continue on test engine with the special prefab spark plug (see Fig. 9).

At the present time proceed the experiments on 2 test SI engine at Department research laboratory on Technical university of Liberec. The objectives of experimental research are the

optimizing of the main design parameters of spark plug with the extension of the central electrode to the integrated combustion chamber (volume of the chamber, number and distribution of the connecting holes in chamber bottom wall between the chamber volume and the engine cylinder volume, design of the central electrode and the production technology of chamber bottom wall).
Next experimental programme with the chamber ignition on SI test engine is set on:

- optimizing of ignition timing for chamber ignition considering to accelerated of burning course of mixture by chamber ignition effects,
- optimizing of design and technological solution of spark plug with the integrated combustion chamber (the figure and technology of the chamber body in bottom wall, the ceramic coating on outer surface of the chamber bottoms),
- verification of the reliability and durability of the spark plug with the integrated combustion chamber and with the extension of the central electrode to the connecting hole at chamber bottom wall.

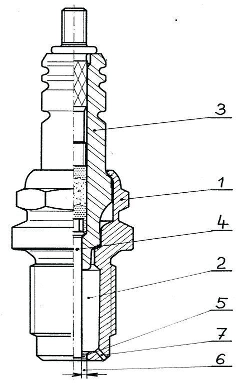


Fig. 4. The new design of the spark plug with the integrated combustion chamber and with the extension of the central electrode to the hole at bottom of chamber wall (the functional sample, made at company BRISK according to our engineering design)

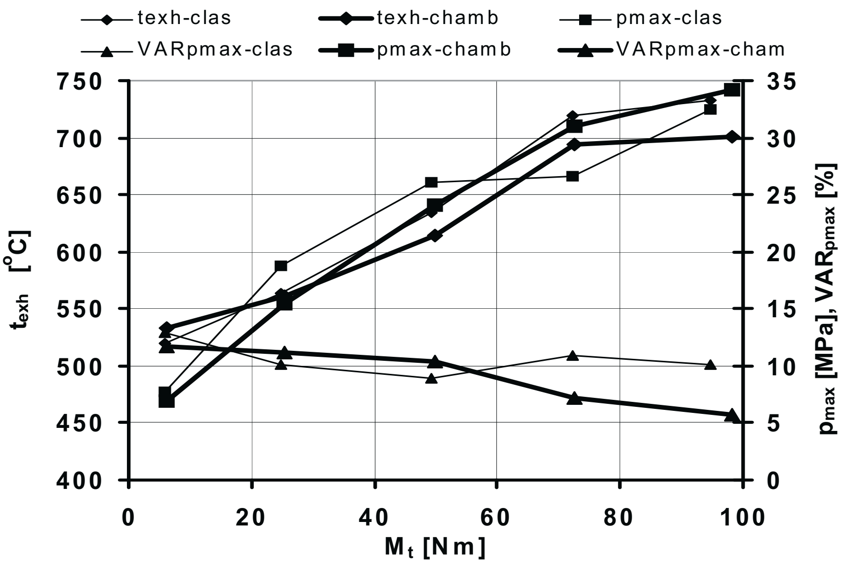


Fig. 5. Load characteristic on n = 2500 RPM: On very low load they are the engine behavior at ignition by the classical spark plug and by spark plug with combustion chamber comparable, for increasing the load the mixture ignition using combustion chamber the total efficiency come to higher. On identical engine adjustment with classical spark plug and spark plug with combustion chamber it has engine with combustion chamber a higher p_{max}, VARpmax step down and the exhaust temperature t_{exh} clearly drops. On full load for identical charge of fuel the middle effective pressure p_e come to higher about 3,5% for engine using chamber ignition

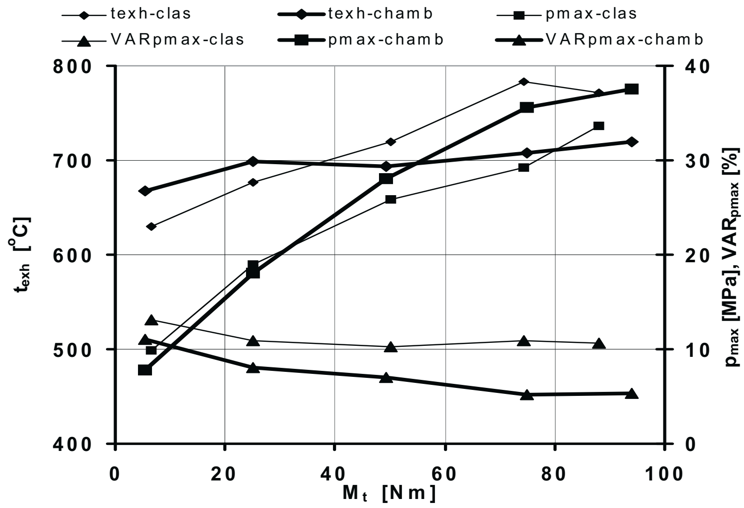


Fig. 6. Load characteristic on n = 4000 RPM: Engine behavior with chamber ignition they are on higher speed a similar like on regime lower speed. On identical engine adjustment both with classical spark plug and chamber ignition the engine with chamber ignition has a higher p_{max}, VARpmax step down and the exhaust temperature t_{exh} clearly drops. On full load for identical charge of fuel the middle effective pressure p_e come to higher about 7% for engine with chamber ignition

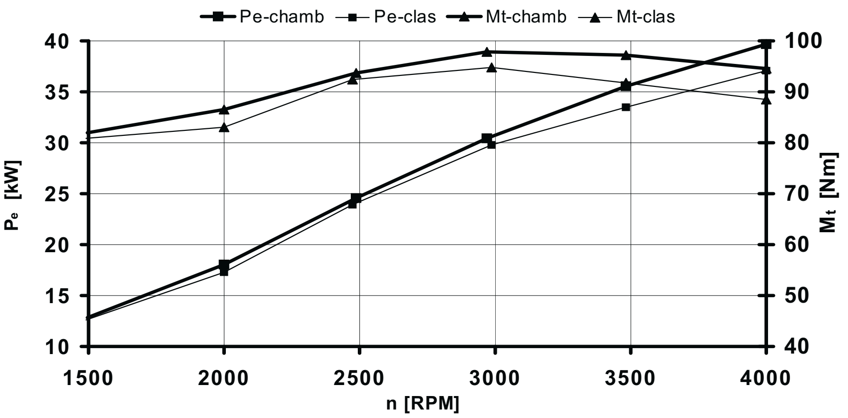


Fig. 7. Speed characteristic on full load: The engine using the spark plug with the integrated combustion chamber (new design) has higher power parameters on all regimes of speed characteristics like engine with classical spark plug. The test engine has the identical setting on full load (ignition timing, fuel charge, mixture richness) for both technique of mixture ignition

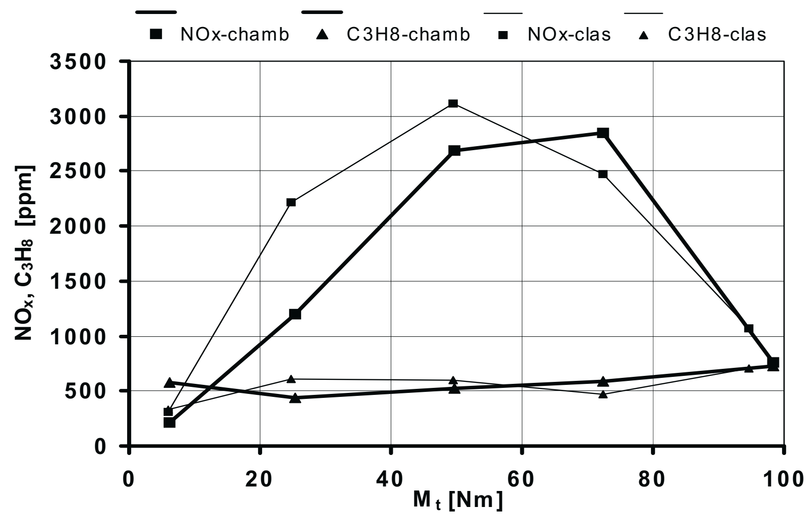


Fig. 8. Emission parameters of the test engine on n = 2500 RPM: The concentration of NOx and unburned HC in exhaust gases before catalyst are practically equivalent both for engine using the spark plug with the integrated combustion chamber (new design) and for the engine with the classical spark plug

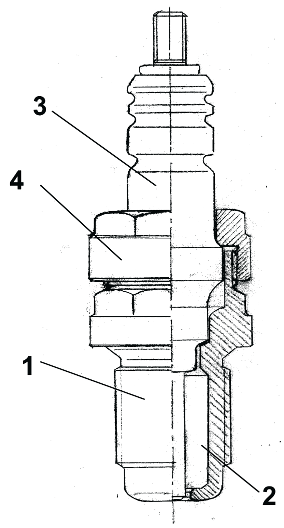


Fig. 9. Special prefab spark plug consist from chamber body 1 with protected chamber volume 2, insulator with packing and with extension of the central electrode 3, that is by nut 4 attachment to the chamber body of spark plug. The chamber body 1 is enclosure by bottom wall with central hole to the insert of the center electrode peak. Difference between diameter of central electrode peak and diameter of central hole in chamber bottom wall creates the space of spark gap. To the bottom wall of the chamber may be place next connecting holes between the chamber volume and the engine cylinder

3. Conclusion

- Results of the measurement on classical spark plug ignition engine with using chamber ignition by very small inside protected volume show, that chamber ignition by fire jet from ignition chamber significantly reduce of working cycle variability SI engine and increase the value of the middle indicated pressure about 5-6% opposite using classical spark plug: it means, that SI engine with chamber ignition works with higher efficiency of heat energy transformation to mechanical work.
- Small ignition chamber using new concept with the extension of the central electrode to the integrated combustion chamber works reliably in of all modes with supply of prepared mixture to chamber by a several small channel from cylinder engine, without special fuel supply into chamber.
- Ignition prepared mixture using chamber ignition with the fire jet to compression volume in engine cylinder increase the velocity of mixture burning in cylinder engine, especially at first phase of combustion process. The energy capacity of the mixture inside the chamber will be about 1,5 J (the energy of the high-voltage discharge is of 10 mJ approximately only). In the closed volume, there may be expected a maintained concentration of the activated particles formed in the focus of the high-voltage discharge (with a minimum thinning due to the turbulent movement in the whole area around the open spark plug). The energy of the burning mixture outflow from the combustion chamber into the compression volume in the cylinder provides a fast propagation of burning in the chamber.
- Experimental results show the chamber ignition like promising ways to increasing of power and efficiency parameters of SI engines: further research must be orientated on optimize design of combustion chamber (size, connecting holes, …) and engine setting (ignition timing, …).

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