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THE INFLUENCE OF THE HYDROGEN INJECTION PARAMETERS ON THE COMBUSTION PROCESS OF IC ENGINE

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Abstract: In order to determine the best injection parameters of hydrogen, an experimental work was performed. The test engine was equipped with the installation for the hydrogen supply, and it was tested how the injection timing and number of injection influence on the combustion process. As the control parameters were taken the engine working stability, as well as the indicating efficiency. It was determined that the injection parameters, significantly influence on the engine working cycle, as well as on the combustion process. The adequate injection timing as well as the adequate number of injections, is crucial, for maintaining the stable work oof the IC engine, as well as for indicating efficiency. In order to provide the stable engine work, with the satisfying indicating efficiency, it is necessary provide multiple injections, more accurate two injections, where one serves to provide the adequate amount of fuel for the working cycle, while the second serves to slowdown the combustion process.
Keywords: IC engine, hydrogen, combustion process, injection parameters

INTRODUCTION

The global concern about the ecology, as well as about the fuel crisis, have forced the engineers to think about the alternatives, which can be used instead the crude oil. In most cases, the electric vehicles are presented as the future of the people mobility. However, the electrification of the entire vehicle park of the world, still has many obstacles, which should overcome. First obstacle is the potential of the production of the electric energy, necessary for the supply and charge of the electric vehicle batteries, as well as necessary infrastructure for this. Second is the recycling of the batteries materials. Then we have the question, do we have enough materials, necessary for the production of the electric vehicle's components. These obstacles impose the question, how can provide the sustainability of the IC engines. The answer is quite simple, it should give more attention to the alternative fuels, which are more ecologically friendly, and to see the possibility of their usage. Many substances can be successfully used as the substitution for the conventional fuels, and that:

- natural gas;
- petroleum gas;
- alcohols;
- biofuels;
- reformulated fuels;
- hydrogen;

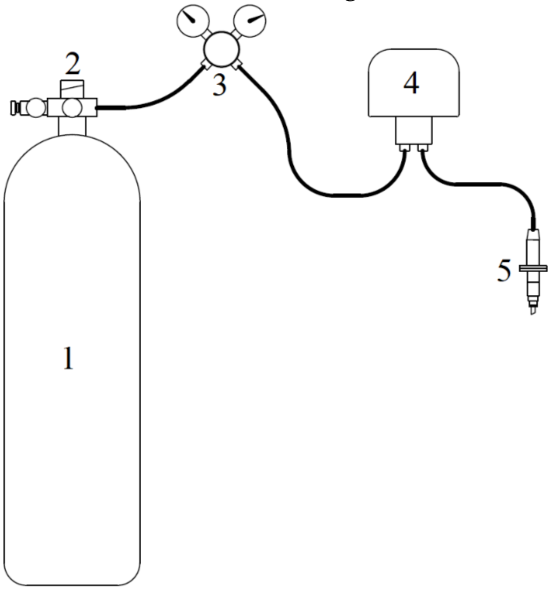
Fuel which in most cases is presented as so–called the fuel of the future is hydrogen. The hydrogen is present in the entire universe, but almost never in free form, as the single chemical element. The main advantage of the hydrogen is its chemical composition, that is, the hydrogen doesn't have carbon in its chemical composition, how the other fuels have. This theoretically means, that is impossible the appearance of harmful components, such are the carbon–monoxide (CO) and unburnt–hydrocarbons (HC).

Because of the mentioned, many researchers work on the subject of hydrogen use as the fuel for IC engines. In most cases, the main problem of hydrogen use, are the high temperatures caused by the high combustion speed [1], and some of the solutions for this undesirable phenomenon are the Exhaust Gas Recirculation (EGR), water injection, blending biodiesel and ignition delay. It is important to say, that more and more researches are focused on the hydrogen direct injection. The main reason for this are the many limitations of the port fuel injection [2], such are pre–ignition, knocking, backfiring, low volumetric efficiency and compression loss problems. All these limitations cause the limitation of engine achievable load and efficiency. Also, many times, the hydrogen use is considering as the fraction of mixture with different fuels. For example, the addition of the hydrogen as the additive, significantly can be influenced on the engine performances [3]. By increment of the hydrogen volume fraction, the knock resistance is enhanced because of the hydrogen high knock resistance and high octane number. Also, this increase causes and the increment of the peak of the heat release rate and of the cylinder pressure. One of the main reasons, why hydrogen in most cases is considered as the additive, and not as the only fuel, is it influence on the formation of nitric–oxygens (NOx). The high amount of hydrogen in mixture leads to the increment of the NOx [4]. This happens due to the high combustion speed, and by this due to the high combustion temperature. So, the main idea is to use mixture, where other fuel will decrease this undesirable phenomenon. By considering many factors such are trend of mitigating climate change worldwide, the contribution of a widespread, reliable and affordable propulsion technology like the IC engine is, it can be said that the future use of IC engines can be very significant, once when the usage of conventional fuels reduces, with the increased use of alternative fuels such is hydrogen. However, it still stays to see how to resolve some of most important things, and that are the availability and production of hydrogen, as well as its safe storage and use [5].

The aim of this paper was to investigate how the injection parameters influence on the combustion process and by that on the IC engine working cycle of the fueled only by hydrogen.

EXPERIMENTAL WORK

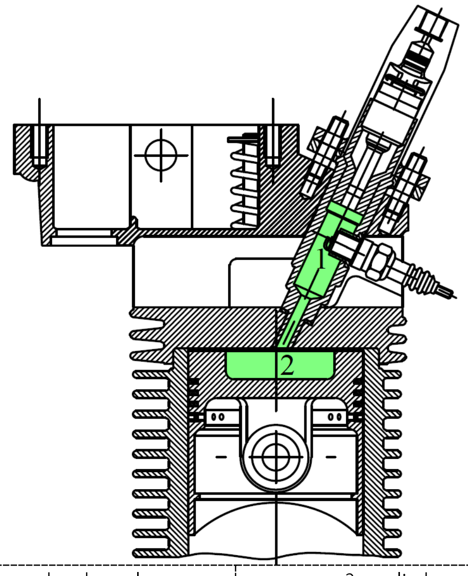
In order to see how the injection parameters influence on the IC engine combustion process, the experimental work was conducted. For the investigation, it was modified the experimental test engine. The basic variant of test engine was diesel engine. For the experimental work, engine was equipped with the ignition system. Also, it was equipped with the gas installation, which scheme and main components can be seen on the Figure 1.



1 – gas tank	3 – valve	4 – pressure regulator
4 – flow meter	5 – prechamber	

Figure 1. Gas installation

The main part of the gas installation is the prechamber, which was made to have the same overall dimensions as the diesel injector, so it was mounted instead the diesel injector. In the prechamber were mounted the spark plug, as well as the Gasoline Direct Injection (GDI) injector, which was used for the injection of the hydrogen. The reason for the use of the prechamber, was the idea to stratify the mixture, in order to reduce the combustion speed of the hydrogen. This was made, because of the fact, that the hydrogen combustion speed is the greatest for the case of the stochiometric mixture, while lean and rich mixture decrease the hydrogen combustion speed significantly [6]. So, by the use of the prechamber, and injection into it, the mixture in prechamber will be always rich, while the mixture in the cylinder will be always lean. By the addition of the prechamber, it was increased the compression volume, and decreased the compression ratio. The compression ratio was first reduced at 13.3:1, but it was found that this value is too high, and due to this, it was replaced and piston so the compression ratio was reduce to 10.4:1. The scheme of the modified engine is shown on the Figure 2, while the engine specifications before and after modifications are given in Table 1.



1 – prechamber volume	2 – cylinder

Figure 2. Modified engine working space

Table 1. Test engine specifications

Name	Value before modification	Value after modification	Unit
Engine bore	85	85	mm
Engine stroke	80	80	mm
Number of cylinders	1	1	–
Displacement	454	454	cm^3
Compression ratio	17.5:1	10.4:1	–

In order to see, how the injection parameters influence on the combustion process, a several injection strategies were tested, and that:

- Injection during the intake stroke;
- Simultaneous injection and combustion;
- Dual–stage injection;

The exact injection parameters are given in Table 2.

Table 2. Injection parameters

Test no.	First injection start, ° BTDC	First injection duration, ms	Second injection start, ° BTDC	Second injection duration, ms
1	344	12	–	–
2	30	12	–	–
3	200	7.2	30	4.8

RESULTS AND DISCUSSION

After the conducted experimental work, from the cylinder pressure it was calculated the heat release rate, Figure 3, which also represents and combustion speed.

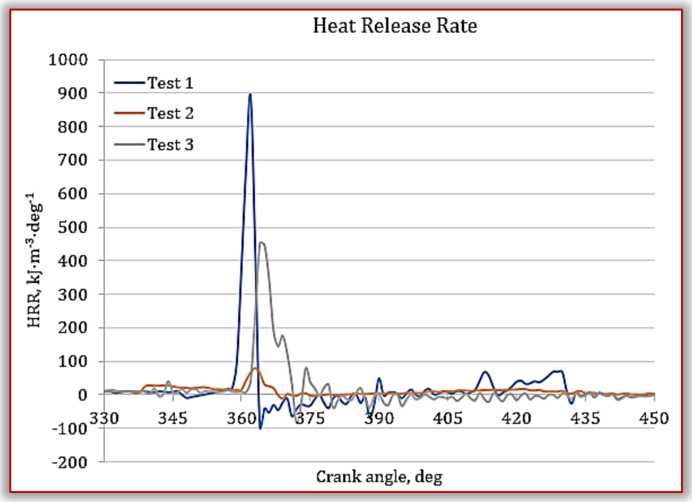


Figure 3. Heat release rate

It was found that the injection parameters, significantly influence on the combustion process. By observing the Figure 3, it can be said that by earlier injection of hydrogen, rises the combustion speed. The reason for this is the formation of more homogenous mixture. The higher combustion speed is followed with better performances due to the higher maximal pressures in the cylinder. However, also it has its negative sides. First of all, during the Test 1 (injection during the intake stroke), it was very hard to start engine with this approach.

The reason for this is a slow engine speed, which allows enough time for the formation of the explosive mixture, which in several case have turned the engine direction, end caused engine stop. Also, during this test, quite often was present the backfire. The reason for this is because was opened the intake valve, and hydrogen exited into the intake port, after which the HHO gas was formatted, which exploded in intake port. Every explosion was followed with pressure wave, which have disabled the intake of air for next cycle, and this caused the unstable engine work.

The Test 2 (simultaneous injection and combustion) have shown as the worst one. During this test, it was impossible to achieve engine load as well as stable regime. Also, the combustion was stretched, what can be seen and from the cumulative heat release, Figure 4.

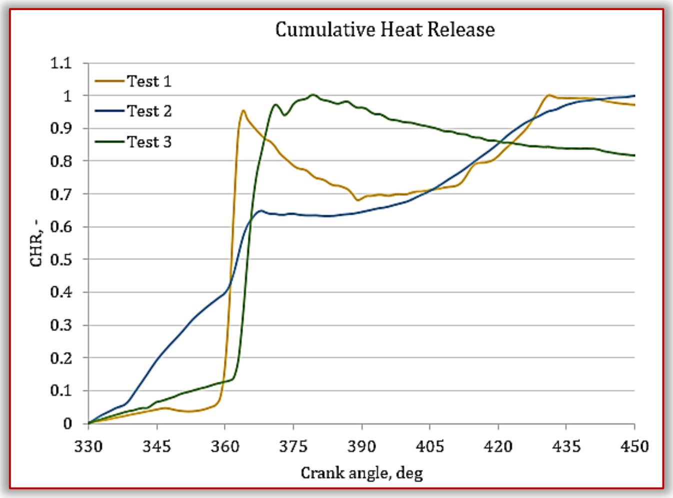


Figure 4. Cumulative heat release

The stretched combustion is specific by low indicating efficiency, which in this case was 22%, while in other two cases was 36% for Test 1, and 34% for Test 3. It can be seen that the center of the combustion (50% of burned mass) is closest to the Top Dead Centre for the Test 1, and due to this, this Test gave the best indicating efficiency.

However, as the best injection parameters, can be ranked the injection parameters used during the Test 3. In this case, the greatest part of the first injection was during the compression stroke, when the intake valve was closed, so in this way, it was avoided the appearance of backfire, and by this was maintained the stable engine work. The role of the second injection was to slow down the combustion, and this was achieved. By slowing down the combustion, are avoided extreme pressure rises ratios, as well as great combustion temperatures. Which means, that this approach is good and from the side of the performances, as well as from the side of the emission, because high temperatures are followed with the rise of NOx, which is the main pollutant in the case of the hydrogen use.

CONCLUSION

It was conducted the experimental investigation of the combustion process, during the engine work with a hydrogen as only fuel. It was found that the injection parameters significantly influence on the combustion process, and by that on the engine work. The best performances can be achieved by early injection, but this can lead to the unstable work, and great mechanical loads. Simultaneous injection and combustion is not recommendable, because doesn't exist enough time for mixture formation, which leads to the stretched combustion and low efficiency. The best solution is multiple injection, where one injection should be during the compression stroke, in order to avoid the backfire, while the second should be defined around the TDC, in order to enrich the mixture, and to slow down the combustion.

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