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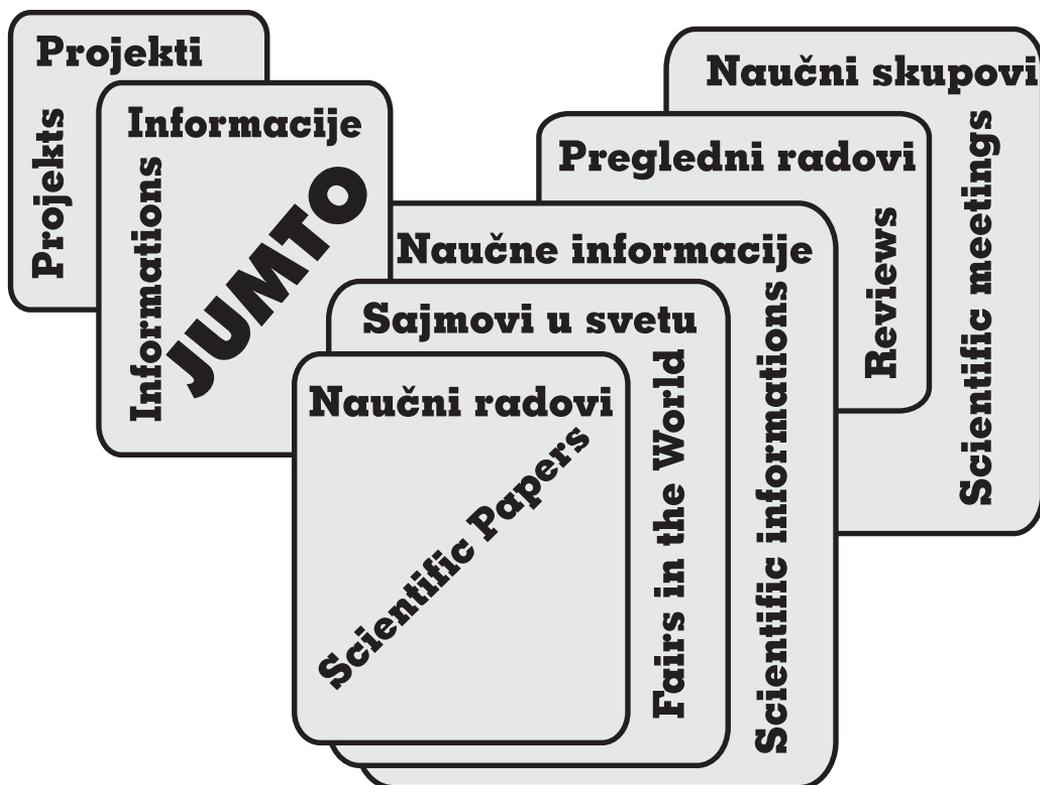
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THE INFLUENCE OF THE HYDROGEN INJECTION PARAMETERS ON THE PERFORMANCES OF THE IC ENGINE

Grujic I.¹, Stojanovic N.², Doric J.³

SUMMARY

In order to determine the best injection parameters for 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 performances of the IC engine. As the control parameters were taken the indicating power as well as the indicating work of the engine. It was determined that the injection parameters, significantly influence on the engine working cycle, and by that on indicating power and indicating work of the engine. The adequate injection timing as well as the adequate number of injections, is crucial, for maintaining the stable work of the IC engine, as well as for obtaining the satisfying engine performances. In order to provide the stable engine work, with the satisfying engine performance parameters, 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, which is crucial in the case of the hydrogen use.

Key words: injection parameters, hydrogen, IC engine, indicating power, indicating work, injection timing.

INTRODUCTION

The global concern about the environment pollution, as well as prognoses that the crude oil will disappear one day, have led the engineers to think about the alternatives, which can be used as the fuel for IC engines. Mostly, the electric vehicles are considered as the future, that is, as the replacement of the vehicles with the conventional powertrains. 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 batterie materials. Then we have the question, do we have enough materials, necessary for the production of the electric vehicle's components. These

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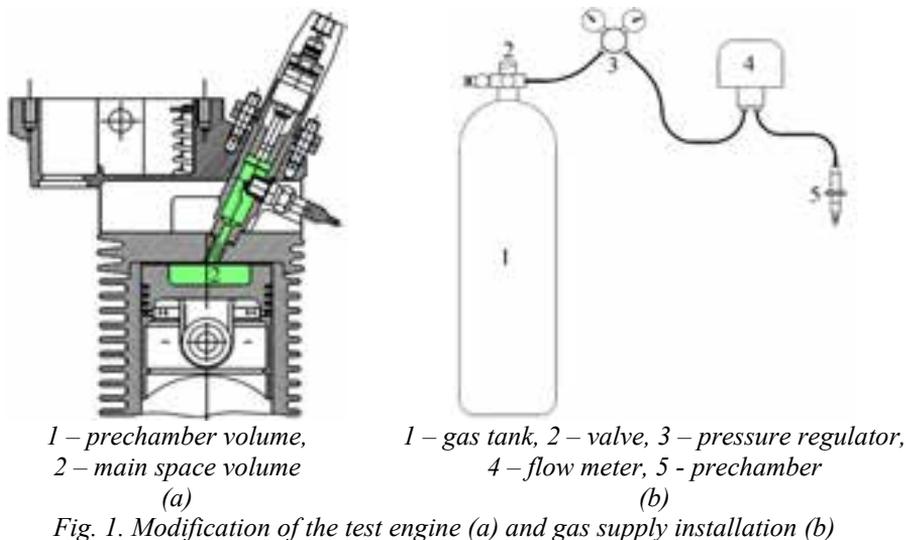
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obstacles impose the question, how can we provide the sustainability of the IC engines, because the easier will be to use a good known technology for which we have potential, than to risk with new one. The answer is quite simple, it should give more attention to the alternative fuels, such as: natural gas, petroleum gas, alcohols, biofuels, reformulated fuels and 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 hydrogen in its chemical composition, doesn't have carbon as chemical component, which is not the case for the other fuels. This theoretically means, that is impossible the appearance of harmful components, such as the carbon-monoxide (CO) and unburnt-hydrocarbons (HC). The main problem of the hydrogen use as the fuel for the IC engines, are high combustion temperatures due to the high combustion speed of the hydrogen [1], and some of the solutions which can be used to mitigate this phenomenon, are the Exhaust Gas Recirculation (EGR), water injection, blending biodiesel and ignition delay. Nowadays, more and more researches are focused on the hydrogen direct injection, as the possible solution for the IC engine work with hydrogen. This is the case due to many limitations of hydrogen port fuel injection [2], such as 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 its 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 as 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 as hydrogen. However, it still stays to see how to resolve some of the 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 performance parameters of the IC engine, that is how the injection parameters of the hydrogen influence on the indicating power and on the indicating work of the IC engine.

EXPERIMENTAL WORK

The experimental investigation of the hydrogen injection parameters influences performances of the IC engine is conducted in the laboratory for the IC engines and fuels at the Faculty of Engineering University of Kragujevac. In order to inject hydrogen to the IC engine, it was used the principle of the prechamber, that is instead the diesel injector is mounted prechamber which consist place for the Gasoline Direct Injection (GDI) injector, as well as for the spark plug (Figure 1 (a)). Also, the engine was equipped with a gas supply installation (Figure 1 (b)).



The addition of the prechamber have changed the geometrical parameters of the IC engine. The main difference between the geometrical parameters of the origin IC engine and modified one is the compression ratio. All other parameters stayed the same, shown in Table 1.

Tab. 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	-

Also, how the origin version of the engine was diesel engine, the engine was equipped with ignition system, in order to provide the ignition of the hydrogen air mixture. 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 and dual-stage injection.

The exact injection parameters are given in Table 2.

Tab. 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, it was found that the injection parameters significantly influence on the IC engine performances. The results for the engine indicating power age given

on the Figure 2, while the results for the indicating work are given on the Figure 3.

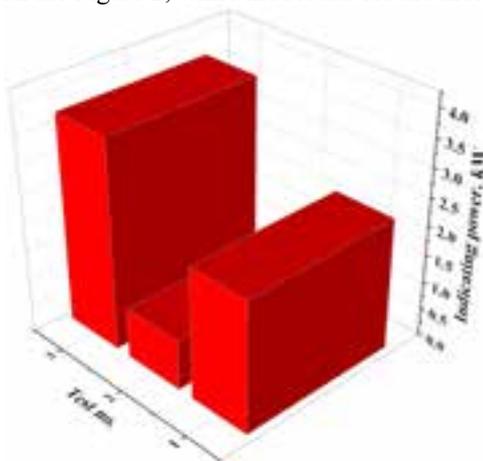


Fig. 2. The results for indicating power

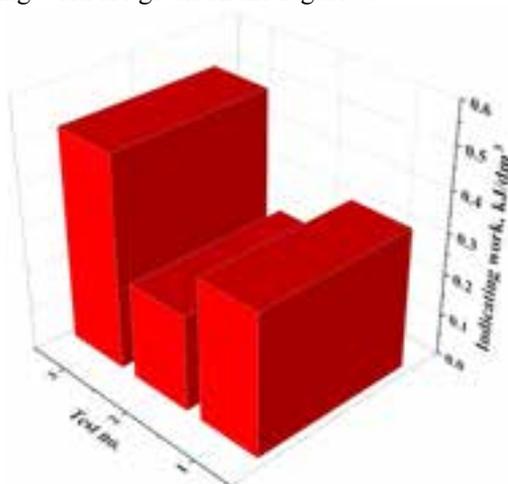


Fig. 3. The results for indicating work

From the results for indicating power, as well as from the results for indicating work, it can be seen that the best results are obtained for the dual-stage injection, while the worst results are obtained for the simultaneous injection and combustion. The reason for good results during the dual-stage injection is because the first injection gives appropriate amount of fuel for working cycle achievement, while the second injection only slowdowns hydrogen combustion. The simultaneous injection and combustion cause too rich mixture in the prechamber and by this combustion speed is too low which causes poor results. In the case of injection during the intake stroke, the amount of fuel is adequate. However, the long time for mixture formation causes a formation of very explosive mixture with too high combustion speed. This causes greater heat losses, and due to this, results are better than in the case of simultaneous injection and combustion, but are worse than in the case of dual-stage injection.

CONCLUSION

The hydrogen can be successfully used as the only fuel for IC engine, no matter to its inconvenient characteristics such as a great combustion speed. The injection parameters can play a significant role in the process of adequate control of the hydrogen combustion process, and by that in achievement of satisfying performances. It was found that from the aspect of the performances, the best solution is to use the dual-stage injection. This allows the injection of adequate amount of fuel during the first injection, for the formation of combustible mixture, while the second injection enriches locally mixture and slowdowns the combustion. The simultaneous injection and combustion, slowdowns combustion too much which negatively influences on the IC engine performances, while the injection during the intake stroke provides a too high combustion speed which is followed with heat losses and unstable engine work.

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