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INVESTIGATION OF THE INFLUENCE OF THE USE OF SMALL HYDROGEN IMPURITIES TO THE MAIN FUEL ON INJECTION SPRAYING

ДОСЛІДЖЕННЯ ВПЛИВУ ВИКОРИСТАННЯ МАЛИХ ДОБАВОК ВОДНЮ ДО ОСНОВНОГО ПАЛИВА НА РОЗПИЛЮВАННЯ ДИЗЕЛЬНОЮ ФОРСУНКОЮ

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Abstract. This paper highlights the possibility of increasing the efficiency of internal matching engines that run on diesel cycle, using added hydrogen to the main fuel in the high-pressure fuel line. To conduct experimental studies of the process of ordering fuel into the engine cylinder using hydrogen additives, an experimental stand was created based on the fuel equipment of the 4CH11/13 engine. A 1.5 kW electric motor is used to start the high-pressure fuel pump. The study was conducted in two stages, on the first site is vibroacoustic substitutes noisy operation of fuel equipment using additional components. Another stage was the optical study of fuel injection parameters by the injector. The Robotron RFT 00024 noise meter was used for acoustic research. Obtained data analysis showed that depending on the presence of a hydrogen additive, a significant effect on the acoustic parameters of the fuel equipment is not observed. Experimental study of the expansion parameters requires the use of high-quality video combining, as one image transmits a significant amount of data about the process of expansion processes than the studied frames (video). Start the process of deploying compatible piles with the addition of the current camera “Xiaomi Yi 4K Action Camera”. This camera allows you to shoot at a frame rate of 120 frames per second with a resolution of up to 4K. The image segmentation method was chosen for white frame processing. This method helps in the sections of the image on the main subconscious foreground and background. With this method, you can display the main jet in the case of a subconscious negative, as well as through indirect tracking of a series of images that affect the change in the structure of the fuel jet. After studying the processed frames, was found that the use of hydrogen additives shortens the fuel flow and increases its volume. The use of small additives is brought to diesel fuel, improves the quality of spraying, as well as pushed and combined by strengthening the drip fuel, which reduces the efficient consumption of the fuel engine.

Key words: internal combustion engine; diesel; hydrogen; small hydrogen additives; fuel spraying research.

У цій роботі висвітлюється можливість підвищення ефективності двигунів внутрішнього згоряння, що працюють за циклом дизеля, з використанням добавок водню до основного палива в паливній магістралі високого тиску. Для проведення експериментальних досліджень процесу впорскування палива в циліндр двигуна з використанням водневих добавок було створено експериментальний стенд на базі паливної апаратури двигуна 4Ч11/13. Для приведення в дію паливного насоса високого тиску використовувався електродвигун потужністю 1,5 кВт. Дослідження проводились у два етапи: перший – проведення віброакустичних замірів шуму роботи паливної апаратури при використанні добавок, другий – оптичне дослідження параметрів розпилювання палива форсункою. Для проведення акустичного дослідження використовувався шумомір «Robotron RFT 00024». Аналіз отриманих даних показав, що від присутності водневої добавки значного впливу на акустичні параметри роботи паливної апаратури не спостерігається. Експериментальне дослідження параметрів розпилю потребує використання високошвидкісного відеобладнання, бо один знімок передає значно менше даних про процес розпилювання, ніж послідовність кадрів (відеозапис). Зйомка процесу розпилювання суміші палива з доданим воднем проводилась камерою «Xiaomi Yi 4K Action Camera». Ця камера дозволяє проводити зйомку з частотою кадрів 120fps з розширенням до 4K. Для обробки кадрів було вибрано метод сегментації зображень. Цей метод полягає в розділенні зображення на основний підсвічений передній план та фон. За допомогою цього методу можна відобразити основний струмінь у вигляді підсвіченого негативу та за допомогою опосередкування серії знімків зробити висновок щодо зміни структури паливного струменя. Після дослідження оброблених кадрів було з'ясовано, що при використанні водневих добавок відбувається укорочення паливного струменя та збільшення його в об'ємі. Застосування малих добавок водню до дизельного палива покращує якість розпилювання, а отже, і сумішоутворення за рахунок подрібнення крапель палива, що призводить до зниження ефективної витрати палива двигуном.

Ключові слова: двигун внутрішнього згоряння; дизель; водень; малі добавки водню; дослідження розпилювання палива.

INTRODUCTION

Limited reserves of fossil organic energy resources necessitate the use of alternative fuels and fuel additives in transport facilities. For the next decades, turbo-piston internal combustion engines (ICE) with compression ignition remain one of the main types of engines for small and medium-sized transport and stationary installations. The problem of ensuring the efficient operation of such engines can be solved using fuel additives.

One of the most promising ways to add hydrogen is using of hydrogen impurities in the main liquid fuel of diesel engines.

Analysis of modern literature has shown that using of hydrogen small impurities to the main fuel, both in the intake manifold [1] and in other ways has a positive effect on the environmental and economic performance of the internal combustion engine. Thus, according to the results of some authors [2, 3], the increase in engine power by 3... 7%, and the decrease in the concentration of CO and CnHm by 10% (27% when using hydrogen additives). The effect of using hydrogen as a fuel additive depends on the method of supply [4], concentration and type of engine.

Currently, many domestic and foreign scientists pay attention to the introduction of hydrogen energy and reducing the impact of exhaust gases on the environment. Among them N.N. Patrakhaltsev, A.E. Whistle, A.R. Rusinov, B.A. Wagner, W.B. Santoso, A. Nur, S. Ariyono, R.A. Bakar, N. Saravanan, Z.H. Kerimov, R.Sh. Misbach, Gomes Antunes J.M., Mikalsen R., Roskilly A.P. and others [5]. In this case, the process of adding small impurities of hydrogen remains the least studied. Analyzing the review of literature sources, not enough information was found on the experimental study of the addition of hydrogen to diesel fuel in the high-pressure line.

THE GOAL OF THE WORK

Investigation of the effects of wave oscillations in high-pressure fuel equipment and the influence of the use of small hydrogen impurities on the spray process and vibroacoustic characteristics of the fuel equipment.

FORMULATION OF THE PROBLEM

Creation of a specialized stand with a computerized system of measurements; research on indicators of the high-pressure fuel system with gaseous additives on the high-pressure line by indirect methods.

As additives to diesel fuel it is possible to use: gas motor fuels (liquefied natural gas, compressed natural gas, liquefied petroleum gases (propane, butane); alcohols and gasoline-alcohol mixtures (methyl, ethyl, isobutyl, etc., alcohols and their mixtures from gasoline in various proportions), esters (methyl tert-butyl ether (MTBE), methyl-tretamyl ether (MTAE), ethyl tert-butyl ether (ETBE), diisopropyl ether) (DIPE), as well as dimethyl ether) (liquid); obtained

from natural gas and coal, biofuels (bioethanol, biodiesel), obtained from renewable raw materials, hydrogen and fuel cells running on hydrogen [6].

Among the proposed options for additives to the main fuel of particular interest is hydrogen, as in accordance with the work of V.A. Wag-ner, A.E. Whistle, M.M. Patrakhaltseva et al., Even minimal hydrogen additives of 0.1-2% by weight have a positive effect on the environmental and economic performance of diesel [7].

However, of particular interest is the addition of hydrogen to the high-pressure fuel line between the high-pressure fuel pump (HPFP) and the injector. The main idea is to add hydrogen to diesel fuel in the high-pressure line at a pressure drop wave using a special device. At the same time, on the compression wave, the diesel fuel is saturated with hydrogen and enters the injector and then injected into the engine cylinder. After injection and reduction of pressure in the cylinder hydrogen is released from diesel fuel, promotes the further crushing of drops, and quickly diffuses in volume of cylinder space. The amount added hydrogen to the cyclic supply of diesel fuel is regulated by the hydrogen pressure at the inlet to the device.

This method is very easy to use and don't require significant intervention in the engine design. However, in the scientific literature, the proposed method of adding hydrogen is little studied, and of particular interest are experimental studies of the small hydrogen additives using in the high-pressure fuel line process and their impact on the internal combustion engine parameters [8].

Therefore, the task of the study was the experimental confirmation of this theory and obtaining qualitative results.

Experimental study

In modern high-speed diesels, the process of fuel delivery takes only 1 ... 4 ms at a high speed of the HPFP plunger. Compression and fuel injection has a pulsed non-stationary nature. Fuel is an elastic medium in which the pressure propagates at a speed close to the speed of sound or exceeding it (1200–1600 m/s), and any, even a slight change in volume in a filled hydraulic system causes a sharp change in pressure [9].

Pressure pulses propagating from the excitation source, encountering interference at the ends of the system, are partially reflected and form return and total waves, greatly distorting the characteristics of the injection. At the end of the fuel supply, pressure waves, reflected from the closed discharge valve, can cause new shocks of the needle after the end of the main injection period. As a result, the so-called re-injection of fuel is undesirable, as the injection pressure is small, and the fuel spray is coarse and inhomogeneous. Feeding with repeated injections leads to an increase in the smoke of the exhaust gases (EG), an increase in soot deposits, an increase in specific fuel consumption and will create the conditions for coking the spray holes [7; 10].

At the end of the fuel supply, the motion and reflection of waves in the high-pressure cavity (pump fitting –

discharge line – injector) gradually fade due to irreversible energy loss due to friction, and the residual pressure is set in it. Usually, the longer the fuel line and the higher the frequency of the injection pulses, the stronger the influence of wave phenomena in the system on the fuel supply characteristics. This factor does not have such an effect on the suction nozzles, where the discharge line is absent, and the wave effect is very small.

The main idea is to add hydrogen to the diesel fuel in the high-pressure line at the pressure drop wave using a special device. In this case, on the pressure injection wave, the diesel fuel is saturated with hydrogen and enters the injector, then the fuel-hydrogen mixture is injected into the engine cylinder. After injection and pressure reduction in the cylinder hydrogen is released from diesel fuel that promotes the further crushing of fuel drops and quickly diffuses in volume of underpiston space. The hydrogen amount that is added to the cyclic supply of diesel fuel is regulated by the pressure of hydrogen at the inlet to the device.

However, in the scientific literature there is not enough information about the results of an experimental study of the addition of hydrogen to the main liquid fuel of the internal combustion engine. Therefore, the task of the study was the experimental confirmation of this theory and obtaining qualitative results.

One of the research methods is physical modeling, which allows to obtain fairly accurate results. The processes of wave oscillations and the possibility of using additives on the vacuum wave require further theoretical and experimental research to determine the conditions of rational parameters of the additive supply and control of the fuel injection process. To study these processes

in detail, an experimental ICE-1-MDV unit based on the D65 diesel fuel system (4CH11/13) was developed and created. The scheme of the experimental setup is presented in Fig. 1. The experimental setup consists of the following subsystems:

- subsystem (based on the fuel system of the engine D65) to study the parameters of fuel injection with the addition of hydrogen gas.
- subsystem for vibroacoustic research.
- subsystem for optical research.
- measurement subsystem.
- subsystem of automation and regulation.

To conduct experimental studies of the diesel internal combustion engine operating fuel injection process with the addition of small hydrogen impurities, a stand was developed based on the diesel fuel system 4CH11/13. A three-phase electric motor with a 1.5 kW capacity was used to drive the standard HPFV.

From the cylinder 1, with a volume of 5 liters, hydrogen enters the valve adding additive 4 through the gearbox 2. The valve 4 is installed in front of the fitting of the standard nozzle 12 mounted on the rod and installed by the spray in the measuring cup 11. High pressure fuel pump (HPFP) 7 is driven by a three-phase AC motor 5 connected via a coupling and operates through a frequency converter to control the speed of the shaft. A digital tachometer is installed on the coupling of the pump and the electric motor. Fuel consumption through the pump was measured on a measuring cup 11. To register the hydrogen pressure, a strain-electric pressure sensor «OVEN PD100-DI6,0» 3.

The pressure value in the fuel line is converted into a current signal by a dynamic fiber-optic pressure sensor for high-temperature pressure measurements “Optrand

Fig. 1. Installation scheme:

- 1 – cylinder with hydrogen; 2 – industrial hydrogen reducer; 3 – pressure sensor; 4 – hydrogen addition valve; 5 – electric motor; 6 – fuel discharge capacity; 7 – HPFV; 8 – expenditure tank; 9 – fuel pump; 10 – computer system for data acquisition and processing; 11 – injection tank; 12 – nozzle; 13 – pressure sensor

AutoPSI-S2000” 13 with an upper measurement limit of 200 MPa and an output signal of 0.5 ... 5 V. This allows you to determine the start of injection fuel, qualitatively assess the value of fuel pressure and investigate the processes in the high-pressure pipeline.

The signals of the primary sensors from the stand ICE-1-MDV are received electronically to the USB-oscilloscope and to the computerized system for measuring and recording data «IRIS» 10.

Vibroacoustic method of research of fuel equipment.

Vibroacoustic study was conducted to investigate the effect of adding hydrogen small impurities to the main fuel on the characteristics of the fuel equipment of a diesel engine. For the study was used noise meter “Robotron RFT 00024” (Fig. 2) with the characteristics given in table. 1. The sensitive element of the noise meter was placed at the closest and safest distance from the elements of the fuel equipment. The noise meter signal was processed in real time using a USB-oscilloscope “IRIS” and displayed on a PC screen.

Considering the peculiarities of sound vibration processing, it was decided to process the maximum and average values of sound oscillations (Fig. 3).

Fig. 2. Robotron RFT 00024 noise meter

According to the results of the obtained data, it is seen that regardless of the presence of the fuel additive, the vibroacoustic parameters of the fuel equipment almost do not change in a wide hydrogen impurity supply pressure range.

Optical examination of fuel equipment.

To study the process of spraying diesel fuel, a stand for high-speed video recording of a jet of sprayed fuel was developed, the scheme of which is shown in Fig. 4.

The control device of the laboratory unit (1) sends a pulse to the control unit, turning on the operation of the HPFV and supplying fuel to the injector (3). The pulse from the sensor (2) is fed to the synchronization unit (5). Thus, the start-up of the camcorder is synchronized with the start of operation of the fuel pump and spray nozzle. The information signal is transmitted to the personal computer (6) via the controller cable from the video camera (4). The fuel jet sprayed on the injector (3) moves parallel to the surface of the screen.

Hydrogen to the high-pressure fuel line came from a cylinder with a residual pressure of 5 MPa.

Table 1. Technical characteristics of the Robotron RFT 00024 noise meter

Level range without switching:	109,9 dB – at A, C and LIN;
with an external filter	69,9 dB
the linear modulation area at this instantaneous reading	10 dB till + 20 dB
linear acoustic frequency range	30 Hz – 20 kHz
Dimensions	340x119x207 mm
Mass	4,7 kg

Video recording was performed using a Xiaomi Yi 4K Action Camera with a scanning frequency of 120fps in 4K mode.

In cases known from the literature, a separate photographic image of the jet is processed. In this paper, the proposed method investigates the brightness of a series images area of fuel jets in their development, while processing is usually subjected to several spray cycles, each of which is from 5 to 15 frames. A series of images is processed automatically. Thus, the method allows us to study the dynamics of changes in the brightness areas of different zones of the jets.

Fig. 3. Diagram of the acoustic oscillation's dependence on the pressure of hydrogen supply

It is suggested to use high-speed video recording for the study, because one frame (photograph) contains much less information about the sawing process than a series of frames (video recording). However, the disadvantage of high-speed video recording is the flickering of the brightness of the frames. Therefore, to prevent brightness flicker, the use of illuminated image negatives was chosen (Fig. 5).

The fuel jet has a vague outline, so defining the boundaries of the fuel jet is a separate task. When analyzing objects in images, the task arises to identify those that are of interest to the researcher. The methods used to find objects of interest are called segmentation methods – the division of the image into the foreground

and background. Segmentation allows you to select areas of the image that seem homogeneous to the observer; this operation divides the image into areas of the same type. There is no universally applicable segmentation method that would give an acceptable result in all images, there is no perfect method of segmentation.

Fig. 4. Scheme of the video recording stand

Image processing of fuel jets.

The computer program “CorelDRAW Graphics Suite” was used to process the registered images of the fuel jet.

According to the idealized description of the fuel jet, it has a conical shape and in its central part is denser than on the periphery. When the fuel jet is evenly filled with drops, it will be depicted in the image in approximately one shade, or vice versa.

This method of research can consider the integral change of the sawing process.

However, after image processing and considering the external characteristics of the fuel jet, the analysis of the obtained images showed that the presence of hydrogen impurities leads to:

- reducing the average diameter of fuel droplets;
- it is recorded that with increasing concentration of gas (air) in the fuel decreases the range of the jet L and increases its width B.
- the contour of the torch acquires a teardrop shape;
- there is no aggravation at its apex, we can assume that to some extent the super-enriched core of the jet is destroyed;
- the angle of opening of a torch considerably increases.

However, these are only indirect research methods, but to study the impact on the processes inside the ICE cylinder, it is necessary to conduct research on a real engine. Conducting such experiments will allow to obtain comprehensive results on the use of small impurities of hydrogen in the fuel of diesel internal combustion engines, as well as to investigate their impact on its economic and environmental characteristics.

CONCLUSIONS

1. The stand for research of the fuel equipment with use of small impurity of hydrogen is developed.
2. When conducting vibroacoustic studies, it was noticed that the use of small impurities of hydrogen does not have a significant effect on the mode of operation of fuel equipment.
3. According to the results of optical research, it is noted that the use of small impurities of hydrogen significantly affects the spraying of fuel, reduces the range of the jet, and leads to a decrease in the average diameter of the fuel droplets.
4. The use of small amounts of hydrogen impurities improves the quality of the mixture by improving fuel spraying, which reduces the specific fuel consumption of the engine.

a)

b)

Fig. 5. Photographs of photofixation of fuel spraying by the injector: a) without additives, b) with a hydrogen additive

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