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MATHEMATICAL SIMULATION OF THE WORKING PROCESS OF THE GAS-DIESEL CYCLE IN THE CYLINDERS OF THE POWERTECH 6068HF250 ENGINE

Today, a trend has been established to expand the use of dual-fuel diesel engines, which is due to their greater efficiency and reduction of toxic emissions into the environment, in particular nitrogen oxides NOx. Modern data from academic research allow us to assert the prospects for the development of the use of gas-diesel engines in agriculture, but there is still no systematic approach to the use of this type of fuel technology. The mathematical model of the working cycle of a gas-diesel makes it possible to determine the optimal indicators in different modes of its load.

The purpose of the research: Calculate and analyze the thermal characteristics of the PowerTech 6068HF250 engine using the Hrynivetskyi-Mazing method in the Mathcad environment.

The main results of the study: The initial performance parameters of the PowerTech 6068HF250 engine in the gas-diesel engine mode turned out to be similar to the performance indicators of this engine in the pure diesel mode. An increase in engine power was detected when using a fuel mixture. The most promising alternative source in the dual-fuel system was the use of liquefied petroleum gas, due to the wide availability of this type of fuel, its economy and the possibility of minimal conversion using gas cylinder equipment up to the 4th generation. The existing data of scientific research by domestic and foreign scientists allow us to state the prospects for the development of the use of gas-diesel engines, but today there is no systematic approach to the use of this type of fuel equipment in agriculture. However, the conversion of serial diesel engines in agricultural tractors to dual-fuel systems with partial replacement of diesel fuel with reduced petroleum gas, which is the most effective way in terms of economy and operational characteristics, remains an open question.

The conclusion of establishing a rational mode of power rationing makes it possible to reduce the dose of spent gas fuel to such an amount that the power is equal to the nominal one.

Keywords: *disel engine, the gas-diesel cycle, operational indicators, liquefied petroleum gas, fuel mixture.*

Formulation of the problem in general its relation to important scientific or practical tasks.

An urgent requirement of modern times in the use of fuel in agriculture is the diversification of sources and the use of alternative to the traditional use of petroleum products, which tend to increase in price [1]. There are several options for using alternative power sources in the design of diesel engines in agriculture [2]. The tendency to expand the use of dual-fuel diesel engines has been revealed, which is due to their higher efficiency and reduction of toxic emissions into the environment, in particular nitrogen oxides NOx [3].

Analysis of the latest research and publications. In addition to liquid fuel, gaseous fuels such as hydrogen, compressed natural gas

(CNG), diesel methyl ether (DME), biogas and LPG can be used in diesel engines [4-8]. Liquefied petroleum gas (LPG) and CNG are now the most popular among gas fuels due to the availability and simplicity of units for their use. These engines, which use conventional diesel and gaseous fuels, are called "dual-fuel engines" [9]. Natural gas and gas derived from biological sources are more attractive alternative fuels for dual-fuel engines due to their environmental nature. When considering gaseous fuels for use in existing diesel engines, a number of issues are important, including the effect of engine operating and design parameters, as well as the type of gaseous fuel, on the performance of dual-fuel engines [10].

The existing data of scientific research by domestic and foreign scientists allow us to state the prospects for the development of the use of gas-diesel engines, but today there is no systematic approach to the use of this type of fuel equipment in agriculture [11]. The conversion of serial diesel engines in agricultural tractors to dual-fuel systems with partial replacement of diesel fuel with reduced petroleum gas remains an open question, which is the most effective way in terms of economy and with preservation of operational characteristics [12]. The mathematical model of the working cycle of a gas diesel makes it possible to establish operational and technological parameters of its work and helps to determine optimal indicators in different modes of its load.

The purpose of the study :

Calculate and analyze the thermal characteristics of the PowerTech 6068HF250 engine according to the Hrynivetsky-Mazing method, using the Mathcad environment.

The main results of the study:

Today, the use of gas in the operation of a diesel engine is carried out according to the principle of the 4th generation gas-cylinder equipment of gasoline engines with insignificant differences regarding the operation of the fuel supply system and their ignition sequence. In contrast to a gasoline engine, where the supply and ignition of gasoline takes place first, and then gas, a dual-fuel diesel engine uses simultaneous supply of both types of fuel entering the cylinder at different operating cycles [1]. Therefore, it is important to accurately calculate the portions of each type of fuel for optimal operation of the engine in dual-fuel mode.. Also, the difficulty of using gas fuel in a diesel engine lies in the specifics of this type of fuel: poor flammability, low methane number, high ignition temperature. It is the above-mentioned features that determine the difficulty of using a diesel engine in combination with natural gas in gas-diesel mode with a clear rationing of the supply of both types of fuel to the cylinders, especially the dose of incendiary diesel fuel, which initiates the ignition of the gas-air mixture [6]. This parameter is especially significant when using modern installations with the use of compressed natural gas during external mixture formation and forced spark ignition, which is modeled in the presented article

The obtained results are presented in Figures 1-3, where the results of the calculations performed in the Mathcad 14 editor are presented. The initial parameters of the performance indicators of the PowerTech 6068HF250 engine in the gas-diesel engine mode are presented in Fig. 1 turned out to be similar to the performance indicators of this engine in purely diesel mode declared by the manufacturer.

We will also note the increase in engine power when using a fuel mixture. This makes it possible to reduce the dose of spent gas (LPG) fuel to such an amount that the power is equal to the nominal one.

Initial data:

$\varepsilon := 17 \quad n := 2400 \quad \alpha := 1.51 \quad To := 293 \quad \omega\text{вп} := 90 \quad \xi := 0.86$

$\phi := 1.05 \quad Po := 0.1 \quad \Delta T := 0 \quad Tr := 810 \quad R\text{п} := 287 \quad n2 := 1.27$

$\lambda := 1.5 \quad S := 0.127$

$Ne := 168 \quad D := 0.10 \quad i := 6 \quad n\text{к} := 2 \quad \tau := 4 \quad \text{квп} := 2.7$

$Qn := 42500 \quad Hn := 98310 \quad \alpha1 := 1.6$

$G\text{ч}1 := \frac{206.5 \cdot Ne}{1000} \quad G\text{ч}1 = 34.692 \quad G\text{ч} := 0.5 \cdot G\text{ч}1$

$G\text{ч} = 17.346 \quad V\text{ч} := G\text{ч}1 \cdot \frac{0.5}{0.94}$

$Log := \frac{1}{0.21} \cdot \left[\left(3 + \frac{8}{4}\right) \cdot 0.5 + \left(4 + \frac{10}{4}\right) \cdot 0.5 \right] \qquad V\text{ч} = 18.453$

$Log = 27.381 \quad Lo := 0.5$

Intake process:

$P\text{к} := 2.2 \cdot Po \quad P\text{к} = 0.22$

$Pr := 0.95 \cdot Pr \quad Pr = 0.209$

$T\text{к} := To \cdot \left(\frac{P\text{к}}{Po}\right)^{\frac{(n\text{к} - 1)}{n\text{к}}} \qquad T\text{к} = 434.589$

$Tg := T\text{к}$

$Tsm := T\text{к}$

$\rho\text{к} := \frac{P\text{к} \cdot 10^6}{R\text{п} \cdot T\text{к}} \quad \rho\text{к} = 1.764$

$\Delta Pa := \frac{\text{квп} \cdot \rho\text{к} \cdot \omega\text{вп}^2 \cdot 10^{-6}}{2} \quad \Delta Pa = 0.019 \quad \frac{\Delta Pa}{P\text{к}} = 0.088$

$Pa := P\text{к} - \Delta Pa \quad Pa = 0.201 \quad \frac{Pa}{P\text{к}} = 0.912$

Fig. 1 Initial parameters and intake process

However, when analyzing the power parameters, effective and specific parameters of the engine at nominal values (Fig. 2), it turned out that in the next simulation of the operation of the engine in the gas-diesel cycle, an increase in engine power by 10.37% was established, which amounted to Nep=185.43 kW in comparison with the similar indicator in the diesel cycle (Fig. 3).

Effective engine parameters

$$W := \frac{S \cdot n}{30} \qquad W = 10.16$$

$$Pm := 0.105 + 0.012 \cdot W \qquad Pm = 0.227$$

$$Pe := Pi - Pm \qquad Pe = 1.379$$

$$\eta m := \frac{Pe}{Pi} \qquad \eta m = 0.859$$

$$\eta e := \eta i \cdot \eta m \qquad \eta e = 0.086$$

$$ge := \frac{3.6 \cdot 10^{6}}{Qn \cdot \eta e} \qquad ge = 984.878$$

Determination of power, dimensions and specific parameters of the engine

$$Vlo := \frac{30 \cdot \tau \cdot Ne}{Pe \cdot 10^{3} \cdot n} \qquad Vlo = 6.089 \times 10^{-3}$$

$$Vho := \frac{Vlo}{i} \qquad Vho = 1.015 \times 10^{-3}$$

$$r := \frac{S}{D} \qquad r = 1.198$$

$$Dp := 100 \cdot \sqrt[3]{\frac{4 \cdot Vho \cdot 10^{3}}{3.14 \cdot r}} \qquad Dp = 102.569 \qquad Sh := Dp \qquad Sh = 122.889$$

$$Vh := \frac{3.14 \cdot D^{2} \cdot S}{4} \qquad Vh = 1.12 \times 10^{-3}$$

$$Nep := \frac{Vh \cdot Pe \cdot n \cdot i \cdot 10^{3}}{30 \cdot \tau} \qquad Nep = 185.432$$

$$\frac{(Nep - Ne) \cdot 100}{Ne} = 10.376$$

Fig. 2 Determination of power, effective and specific engine parameters at nominal values

During the mathematical modeling of the use of the PowerTech 6068HF250 engine in the gas-diesel cycle, an increase in the nominal power of the engine to Nep=185.432 kW was established, which was 10.376% more compared to this indicator in the diesel mode.

$$Fp := \frac{3.14 \cdot D^{2} \cdot 10^{4}}{4} \qquad Fp = 88.203$$

$$Vp := Vh \cdot i \qquad Vp = 6.721 \times 10^{-3}$$

$$Me := \frac{9550 \cdot Ne}{n} \qquad Me = 668.5$$

$$Gt := \frac{Nep \cdot ge}{1000} \qquad Gt = 182.628$$

$$Nl := \frac{Nep}{Vh \cdot i} \qquad Nl = 2.759 \times 10^{4}$$

$$Np := \frac{Nep \cdot 100}{Fp \cdot i} \qquad Np = 35.039$$

Fig. 3 Determination of nominal power

When using the mathematical model of the PowerTech 6068HF250 diesel engine in the Mathcad 14 environment, it was established that the nominal power in the diesel cycle was Nep=162.72 kW, which was 3.13% less than the declared power of the engine by the manufacturer.

During the next simulation of the engine operation in the gas-diesel cycle, an increase in engine power by 10.37% was found, which amounted to Nep=185.43 kW compared to a similar indicator in the diesel cycle.

We will also note the increase in engine power when using a fuel mixture. This makes it possible to reduce the dose of spent gas (LPG) fuel to such an amount that the power is equal to the nominal one.

The most promising alternative source in the dual-fuel system was the use of liquefied petroleum gas, due to the wide availability of this type of fuel, its economy and the possibility of minimal conversion using gas cylinder equipment up to the 4th generation. Regarding practical recommendations for the use of liquefied petroleum gas, it is justified to switch to a diesel cycle from a dual-fuel cycle when the load is reduced by 30% from the nominal one, the optimal ratio when working in a gas-diesel cycle with diesel fuel is 50% of liquefied petroleum gas.

In gas-phase LPG diesel engines, vaporized LPG is fed into the cylinder with intake air and the LPG-air mixture is compressed as in a conventional diesel engine. LPG-air mixture is not self-igniting due to high self-ignition temperature. A small amount of diesel fuel, called pilot, is injected to ignite the LPG-air mixture. Pilot diesel, which is injected by conventional diesel injection equipment, only reduces a small fraction of the engine's power output

To compensate for the increase in the cost of traditional fuel in recent years, domestic and foreign researchers have proposed a number of improvements and alternative types of fuel, however, for agricultural machinery with the predominant use of diesel engines and the existing machine-tractor fleet, one of the most promising was the conversion of a conventional diesel engine for the use of additional types of fuel, of which the most profitable is the use of liquefied gas. The existing data of scientific research by domestic and foreign scientists allow us to state the prospects for the development of the use of gas-diesel engines, but today there is no systematic approach to the use of this type of fuel equipment in agriculture. However, the conversion of serial diesel engines in agricultural tractors to dual-fuel systems with partial replacement of diesel fuel with reduced petroleum gas, which is the most effective way in terms of economy and operational characteristics, remains an open question.

Installing gas on diesel seems justified for several reasons:

- is cost savings without loss of engine power;

- is a decrease for soot in the cylinders because gas fuel contains fewer impurities;

- Improvement of environmental performance of the engine due to reduction of toxic emissions into the atmosphere

Conclusion

The main performance indicators of the PowerTech 6068HF250 engine in the gas-diesel cycle turned out to be similar to the indicators set by the manufacturer for a purely diesel mode. In the gas-diesel cycle of using the PowerTech 6068HF250 engine, an increase in engine power was found when using a mixture of fuels. The absorption of the rational mode of power rationing makes it possible to reduce the dose of spent gas (LPG) fuel to such an amount that the power is equal to the nominal one.

References

1. Zakharchuk, V., Zakharchuk, O., Skalyga, M., Kuts, N., & Yaroschuk, V. (2024). Improving environmental indicators of the wheeled tractor diesel engine by using biofuels. *Eastern-European Journal of Enterprise Technologies*, *2*(10 (128), 51–58 [in English].

2. Zhang, Z., Li, J., Tian, J., Dong, R., Zou, Z., Gao, S., & Tan, D. (2022). Performance, combustion and emission characteristics investigations on a diesel engine fueled with diesel/ethanol/n-butanol blends. *Energy*, *249*, 123733 [in English]..

3. Shi, Z., Wang, J., Guo, X., & Liu, X. (2023). Multi-Objective Optimization of the Structural Design of a Combustion Chamber of a Small Agricultural Diesel Engine Fueled with B20 Blend Fuel at a High Altitude Area. *Sustainability*, *15*(15), 11617 [in English]..

4. Mathur, S., Waswani, H., Singh, D., & Ranjan, R. (2022). Alternative fuels for agriculture sustainability: Carbon footprint and economic feasibility. AgriEngineering, 4(4), 993-1015 [in English]..

5. Mateichyk, V., Kostian, N., Smieszek, M., Gritsuk, I., & Verbovskyi, V. (2023). Review of Methods for Evaluating the Energy Efficiency of Vehicles with Conventional and Alternative Power Plants.Energies, 16(17), 6331 [in English]..

6. Abbasi, S., Bahrami, H., Ghobadian, B., & Kiani Deh Kiani, M. (2018). Energy analysis of a diesel engine using diesel and biodiesel from waste cooking oil.Journal of Agricultural Machinery, 8(1), 149-157 [in English]..

7. Mederle, M., Urban, A., Fischer, H., Hufnagel, U., & Bernhardt, H. (2015). Optimization potential of a standard tractor in road transportation.landtechnik, 70(5), 194-202 [in English]..

8. Nadykto, V., Findura, P., Kyurchev, V., & Orel, O. (2022). Influence of Biodiesel on Performance of Machine-Tractor Units.Acta technologica agriculturae, 25(1), 7-12 [in English]..

9. Schlosser, J. F., Farias, M. S. D., Bertollo, G. M., Russini, A., Herzog, D., & Casali, L. (2020). Agricultural tractor engines from the perspective of Agriculture 4.0. Revista Ciência Agronômica, 51(spe), e20207716 [in English]..

10. Pham, Q., Park, S., Agarwal, A. K., & Park, S. (2022). Review of dual-fuel combustion in the compression-ignition engine: Spray, combustion, and emission. Energy, 123778 https://doi.org/10.1016/j.energy.2022.123778

11. Tashev, A., & Dimitrov, E. (2022, September). LPG effect on performance parameters of diesel engine operated on dual-fuel mode. In AIP Conference Proceedings (Vol. 2449, No. 1).AIP Publishing [in English].

12. Kryshtopa, S., Panchuk, M., Kozak, F., Dolishnii, B., Mykytii, I., & Skalatska, O. (2018). Fuel economy raising of alternative fuel converted diesel engines. Eastern-European Journal of Enterprise Technologies, 4(8), 6-13 [in English].

МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ РОБОЧОГО ПРОЦЕСУ ГАЗОДИЗЕЛЬНОГО ЦИКЛУ В ЦИЛІНДРАХ ДВИГУНА POWERTECH 6068HF250

Актуальною вимогою сучасності у використанні палива в сільському господарстві є диверсифікація джерел і використання альтернативних традиційному використанню нафтопродуктів, які мають тенденцію до подорожчання. Виявлено тенденцію до розширення використання двопаливних дизельних двигунів, що зумовлено їх більшою економічністю та зменшенням токсичних викидів у навколишнє середовище, зокрема оксидів азоту NOx При розгляді газоподібного палива для використання в існуючих дизельних двигунах важливий ряд питань, включаючи вплив робочих і конструктивних параметрів двигуна, а також типу газоподібного палива на продуктивність двопаливних двигунів . Наявні дані наукових досліджень вітчизняних та зарубіжних вчених дозволяють стверджувати про перспективність розвитку використання газодизельних двигунів, але на сьогоднішній день відсутній системний підхід до використання цього виду паливної техніки в сільському господарстві. Математична модель робочого циклу газодизеля дає змогу встановити експлуатаційно-технологічні параметри його роботи та допомагає визначити оптимальні показники в різних режимах його навантаження.

Розрахувати та проаналізувати теплові характеристики двигуна PowerTech

6068HF250 за методом Гринівецького-Мазінга в середовищі Mathcad.

Вихідні параметри показників роботи двигуна PowerTech 6068HF250 в режимі газодизельного двигуна, наведені иявилися схожими із заявленими виробником показниками роботи цього двигуна в чисто дизельному режимі. Виявлено збільшення потужності двигуна при використанні паливної суміші газ- дизель.

Найбільш перспективним щодо альтернативного джерела в двопаливній системі, виявилось використання зрідженого нафтового газу, в зв'язку із широкою доступністю даного виду палива, його економічністю та можливістю мінімального переобладнання з застосуванням газобалонного обладнання до 4 покоління. Існуючі дані наукових досліджень вітчизняних та зарубіжних науковців дозволяють заявити про перспективність розвитку використання газодизельних двигунів, однак на сьогодні відсутній систематизований підхід щодо використання даного типу паливного обладнання в сільському господарстві. Проте залишається відкритим питанням переобладнання серійних дизельних двигунів в сільськогосподарських тракторів в двопаливні з частковим заміщенням дизельного пального зріженим нафтовим газом, що є найбільш ефективним способом щодо економічності та експлуатаційних характеристик.

Встановлення раціонального режиму нормування потужності дає змогу зменшити дозу відпрацьованого газового палива до такої кількості, щоб потужність була рівною номінальній.

Ключові слова: *дизельний двигун, газодизельний цикл, експлуатаційні показники, зріджений нафтовий газ, суміш палив.*

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