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OPTIMIZATION BIOFUEL CONSUMPTION THROUGH THE DEVELOPMENT OF AN ADAPTIVE CONTROL ALGORITHM

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The article discusses modern approaches to improving the efficiency of machine-tractor units by optimizing fuel consumption using a fuel component mixer. Rising fuel prices and tightening environmental requirements encourage the search for new technologies that ensure economical and environmentally friendly operation of agricultural machinery. One of the promising solutions is the use of power systems with a fuel mixer, which allows you to adjust the ratio of fuel mixture components in real time, taking into account the load on the engine, its speed and temperature regimes.

The article analyzes in detail the influence of various parameters of the fuel mixture on the efficiency of the engine and its economy. A mathematical model of the fuel mixing process is proposed, which takes into account the physicochemical properties of the components, as well as a control algorithm that allows adaptively adjusting the fuel mixture to achieve optimal consumption indicators. Computer modeling of the engine operation using different fuel mixture compositions was carried out, which made it possible to assess the influence of the mixer on the dynamic characteristics of the unit and fuel economy.

The results of the research show that the use of a fuel mixer allows you to reduce costs by 10-15% without losing power, while maintaining the stability of engine operation. In addition, it was possible to reduce emissions of harmful substances into the atmosphere, which contributes to increasing the environmental friendliness of agricultural work. The article also provides recommendations for setting up and operating a fuel mixing system to achieve maximum efficiency.

The proposed approach may be useful for engineers involved in the development of fuel systems, as well as for farmers seeking to reduce operating costs. The results obtained contribute to the further development of energy-efficient technologies in agricultural machinery.

Key words: *fuel consumption optimization, machine-tractor unit, fuel mixer, fuel system, fuel economy, control algorithm, fuel mixture, energy efficiency, agricultural machinery.*

Eq. 1. Fig. 2. Table. 1. Ref. 9.

1. Problem formulation

Modern agriculture requires not only high productivity from machinery, but also economic efficiency and environmental safety. One of the main items of expenditure when operating machine-tractor units is fuel, the cost of which is constantly growing. In addition, the tightening of environmental standards encourages manufacturers of agricultural machinery to look for new ways to reduce harmful emissions into the atmosphere [1]. In this context, the task of optimizing fuel consumption without losing power and productivity of machinery becomes particularly relevant.

One of the promising directions for solving this problem is the use of fuel systems with a fuel mixer. This approach allows you to effectively manage the composition of the fuel mixture, adapting it to different engine operating modes. The fuel mixer ensures the rational use of energy resources due to the optimal ratio of fuel mixture components, which contributes to reducing fuel consumption and reducing emissions of harmful substances.

The purpose of this study is to develop an algorithm for optimal control of a fuel supply system with a fuel mixer for machine-tractor units. The article considers the main factors affecting the efficiency of the fuel system, and proposes a mathematical model of the fuel mixing process. Special attention is paid to computer modeling, which allows you to evaluate the dynamic characteristics of the unit and find optimal settings for different operating modes.

Current trends in the energy sector are focused on increasing the efficiency of renewable energy sources, among which biofuels occupy a significant place. However, despite the environmental benefits, biofuel consumption remains significant, which affects the economic feasibility of its use. Existing control systems do not fully take into account dynamic changes in operating conditions, which leads to inefficient fuel use.

One of the main problems is the lack of adaptive control algorithms that could quickly respond to changes in external and internal factors, such as load, ambient temperature and parameters of the biofuel itself. The imperfection of traditional control methods leads to overconsumption of fuel and increased operating costs.

Thus, the issue of developing an adaptive control algorithm that will optimize biofuel consumption by dynamically adjusting the system's operating modes is relevant. This will contribute to increasing the economic efficiency and environmental safety of biofuel use.

2. Analysis of recent research and publications

In recent years, there has been significant interest in developing efficient power systems for machine-tractor units aimed at optimizing fuel consumption and reducing emissions of harmful substances into the atmosphere. Current research focuses on the use of fuel mixers, which allow adaptively regulating the composition of the fuel mixture depending on the engine operating mode and external operating conditions.

According to studies [1], the use of a fuel mixer in diesel engines allows to achieve a reduction in fuel consumption by 12-15% while simultaneously reducing emissions of nitrogen oxides and soot. They propose a fuel system control algorithm that takes into account the load on the engine and optimizes the ratio of diesel fuel and biocomponents. A similar approach is also considered in work [2], which investigates the effect of changing the composition of the fuel mixture on the dynamic characteristics of the engine. The results showed that the use of multicomponent fuel mixtures allows to increase energy efficiency by 10-12%.

Researchers [3] focus on mathematical modeling of the fuel mixing process using different types of bioadditives. They propose an improved model that takes into account the physicochemical properties of the components and their influence on the combustion process. The use of such a model allows for adaptive adjustment of the fuel mixture in real time, increasing engine efficiency.

The study [4] examines the environmental aspects of using fuel mixers. The results show that optimizing the composition of the fuel mixture allows reducing carbon dioxide emissions by 8-10%, which contributes to reducing the impact on the environment. This confirms the prospects for using fuel mixers in conditions of tightening environmental standards.

Despite the positive results, the research also revealed certain challenges. In particular, the need to ensure engine stability when using multi-component mixtures and the difficulty of implementing adaptive control algorithms in real-world operating conditions. However, the development of computer modeling and the introduction of artificial intelligence into fuel systems opens up new opportunities to overcome these limitations.

3. The purpose of the article

The aim of the article is to develop and implement an adaptive control algorithm for optimizing biofuel consumption in energy systems. This involves analyzing dynamic operating conditions, identifying key factors affecting fuel efficiency, and creating an algorithm model that can respond quickly to changes in external and internal parameters. The implementation of such an approach will contribute to reducing operating costs, increasing economic efficiency, and reducing the environmental burden on the environment.

4. Results and discussion

Machine-tractor units operate in conditions of constant change of thermal, load and speed regimes. Internal combustion engines during operation often function in unstable regimes, such as starting, warming up, acceleration, braking, load change and stopping. This requires adaptive control of engine operating processes, especially when using a mixture of diesel fuel (DP) and biofuel (BP), where it is necessary to automatically adjust the composition of the fuel mixture depending on the current operating modes.

A feature of diesel engines is their dynamic asymmetry, which manifests itself in different behavior when the load increases or decreases, as well as when starting and stopping. This means that the processes in the engine have a different nature depending on the direction of the load or speed change. Therefore, the fuel system control algorithm must take these features into account, ensuring stability and efficiency of operation under different operating conditions [5].

Optimization of fuel consumption in machine-tractor units is achieved by using a mixer, which allows you to adjust the composition of the fuel mixture in real time. To do this, it is necessary to control a number of technical indicators, such as torque, crankshaft speed, power, coolant and power unit temperature, as well as the percentage composition of the fuel mixture. In addition, it is important to take into account economic indicators (fuel consumption) and environmental parameters (composition and amount of harmful emissions).

Since the calorific value of biofuels is lower than that of diesel fuel, a larger volume of fuel must be supplied to provide the same engine power. Therefore, when operating on a mixture of diesel and gasoline, it is important to adjust the cyclic fuel supply to maintain engine power and dynamic characteristics. This requires precise adjustment of the fuel mixture composition in accordance with the current loads and operating modes.

The developed control algorithm provides for flexible adjustment of the percentage composition of the fuel mixture depending on the following factors:

- minimization of specific fuel consumption;
- achieving the required engine power;
- optimal ratio of fuel mixture components;
- ensuring the efficiency of work processes;
- maximum use of biofuels to reduce harmful emissions.

The engine is usually started on diesel fuel, as biofuels have a higher viscosity and density, as well as higher pour points. This impairs evaporation and the combustion process on a cold engine. After warming up to the optimum temperature, the system switches to operating on a fuel mixture. If the biofuel temperature drops below a set threshold, the engine automatically switches back to diesel fuel.

Optimization of the fuel mixture composition is carried out using an electronic control system that analyzes the current parameters (power, torque, speed) and adjusts the biofuel content depending on the operating mode. When the load increases, the proportion of diesel fuel increases to ensure stable power, and when the load decreases, the biofuel content increases to save costs and reduce harmful emissions [6].

The algorithm development process took into account the inertia of the fuel system, which can delay the supply of a new fuel mixture composition to the engine cylinders Fig. 1. To avoid fluctuations in engine operation, the mixture composition is adjusted taking into account long-term changes in operating modes, which ensures stable engine operation.

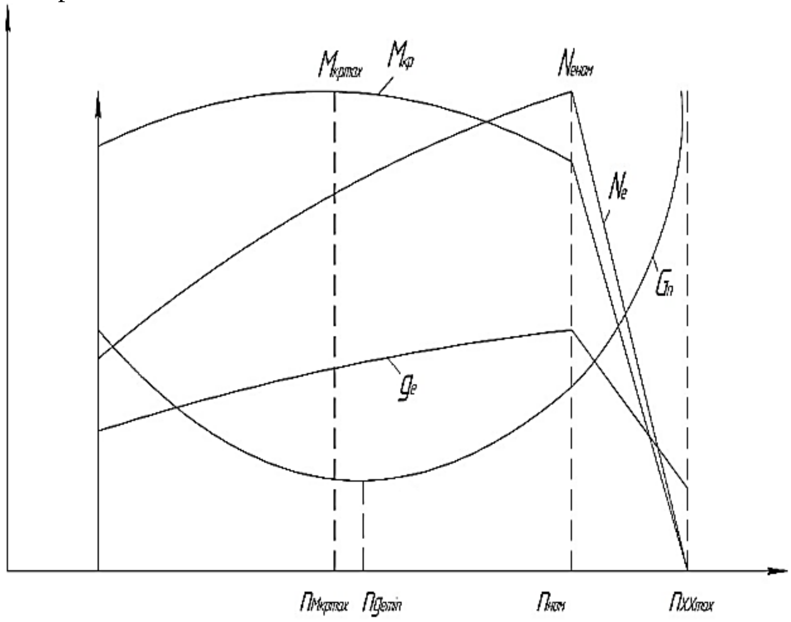

Fig. 1. Calculation scheme for building an algorithm for the functioning of a machine-tractor unit

Thus, the implementation of a control algorithm with a fuel mixer allows you to optimize fuel consumption, reduce emissions of harmful substances and increase the efficiency of machine-tractor units. This makes the use of fuel mixers a promising direction in the development of agricultural machinery, as it provides a balance between power, economy and environmental friendliness.

The rational percentage ratio of DP and BP in the composition of the mixed fuel provides effective technical indicators during the performance of various works. This ratio is selected depending on the current engine operating mode, load and external conditions. The control algorithm involves the use of the maximum proportion of BP, which is able to provide the required torque, effective power, hourly consumption and engine speed without deterioration of dynamic characteristics.

To achieve optimal efficiency, the control system calculates the specific effective consumption of the fuel mixture in real time, focusing on the minimum values with the highest BP content. The following parameters are taken into account:

- engine torque;
- crankshaft rotation speed;
- effective power;
- coolant and power supply temperature;
- composition of harmful emissions.

When operating at low and medium loads, the use of a mixture with a high content of BP allows you to achieve fuel savings due to lower specific consumption. This is due to the lower calorific value of BP compared to DP, which is compensated by an increase in the volume of cyclic fuel supply. In this case, the electronic control system adjusts the fuel supply, ensuring the necessary power and stable engine operation [7].

Under high loads and when operating at maximum power, the algorithm automatically increases the proportion of diesel in the fuel mixture to ensure sufficient combustion heat. This allows you to maintain the dynamic characteristics of the engine and avoid overheating. At the same time, an optimal balance between economy and performance of the machine unit is achieved.

The transition between different percentages of DP and BP occurs gradually to avoid fluctuations in engine operation. For this purpose, the algorithm provides a special adaptive module that smooths out changes in the composition of the fuel mixture. This allows for stable operation even with sudden changes in operating mode or load.

In addition to economic efficiency, the proposed method contributes to improving environmental performance. The use of BP allows reducing emissions of carbon dioxide, nitrogen oxides and soot, which reduces the negative impact on the environment. This is especially true for agricultural machinery operating in open areas.

The algorithm also takes into account the inertia of the fuel system, which limits the speed of response to changes in operating modes. To avoid delays in supplying a new mixture composition to the engine cylinders, control is carried out based on predicted changes in load and speed. This allows for increased control accuracy and reduced fluctuations in technical indicators.

$$\begin{gathered}\frac{dP(t)}{dt}=\frac{d}{dt}\left(\frac{M(t)\cdot n(t)}{9.5488}\right)\\ C_r\cdot m_r\frac{dT_r(t)}{dt}=P_{heat}(t)-k_{cool}\cdot(T_r(t)-T_{ambient})\\ C_{BP}\cdot m_{BP}\frac{dT_{BP}(t)}{dt}=P_{transmission}(t)-k_{transmission}\cdot(T_{BP}(t)-T_{ambient})\\ \frac{dE(t)}{dt}=k_1\cdot P(t)+k_2\cdot T_r(t)+k_3\cdot T_{BP}(t)+k_4\cdot n(t)\end{gathered}\tag{1}$$

where P(t) – power (kW) at time t; M(t) – torque (N·m) at time t; C_r – heat capacity of the coolant (J/kg°C); n(t) – crankshaft rotation frequency (rpm) at time t; m_r– mass of coolant (kg); $T_r(t)$ – coolant temperature at time t (°C); $P_{heat}(t)$ – the amount of heat produced by the engine (W); k_{cool} – heat transfer coefficient (W/°C); $T_{ambient}$ – ambient temperature (°C); C_{BP} – heat capacity of oil in BP (J/kg°C); m_{BP} – mass of oil in BP (kg); $T_{BP}(t)$BP temperature at time t (°C); $P_{transmission}$(t) – the amount of heat generated in the power supply (W); k_1 ,k_2 ,k_3 ,k_4 – coefficients that take into account the impact of each parameter on the emission level.

This system of equations allows you to model changes in power, temperature, and emission levels based on unit parameters.

Here is a structured algorithm for the functioning of a machine-tractor unit in the form of table 1. The table shows the main stages and mathematical equations for each stage.

Table 1.

Structured algorithm for the functioning of a machine-tractor unit

Step	Action	Description	Mathematical equation
1	Calculation power	Calculation capacity based on torque and frequency revolutions.	$\frac{dP(t)}{dt}=\frac{d}{dt}\left(\frac{M(t)\cdot n(t)}{9.5488}\right)$
2	Calculation temperatures cooling liquids	Rating changes temperatures cooling liquids depending from the heat that produces engine, and the heat that is given.	$C_r\cdot m_r\frac{dT_r(t)}{dt}=P_{heat}(t)-k_{cool}\cdot(T_r(t)-T_{ambient})$
3	Calculation BP temperatures	Rating changes transmission unit temperature.	$C_{BP}\cdot m_{BP}\frac{dT_{BP}(t)}{dt}=P_{transmission}(t)-k_{transmission}\cdot(T_{BP}(t)-T_{ambient})$
4	Pest control emissions	Calculation equal harmful emissions, depending from power, temperature and speed.	$\frac{dE(t)}{dt}=k_1\cdot P(t)+k_2\cdot T_r(t)+k_3\cdot T_{BP}(t)+k_4\cdot n(t)$
5	Regulation cooling	On / Off systems cooling depending from temperatures cooling liquids.	$Q_{cool}(t)=k_{cool}\cdot(T_r(t)-T_{ambient})$
6	Support optimal temperatures	Regulation temperatures within optimal limits values to prevent overheating.	$T_r(t)\approx 75\ {\circ}C-95\ {\circ}C$ $T_{BP}(t)\approx 85\ {\circ}C-95\ {\circ}C$
7	Support environmental standards	Level control harmful emissions and automatic decrease power in case exceeding the norms.	If $E(t) > E_{norm}$ we reduce P(t) and n(t)
8	Analysis efficiency works	Rating efficiency of the unit, taking into account power, temperature and level emissions.	$\eta(t)=P(t)\backslash P_{input}$, where P_{input} is the input power .
9	Detection malfunctions and accidents	Monitoring temperature and level emissions for detection emergency situations.	If $T_r(t)>100\ {\circ}$ C or $E(t) > E_{max}$, we generate an alarm signal .

The algorithm for the functioning of a machine-tractor unit is based on several key principles that ensure efficiency, safety and compliance with environmental requirements. First of all, the calculation power engine is important stage, because from him depends the ability of the unit to perform the required work [8]. Power determined by torque and speed crankshaft, and the correct its calculation allows to provide proper performance at optimal expenses fuel. If power will not be calculated accurately, the unit may to work in an overloaded or ineffective mode that will lead to unnecessary expenses fuel or mechanical damage.

Further an important aspect is the temperature of the coolant fluids. Engine needs proper cooling to prevent overheating, because excessive temperature can lead to breakdowns and decline efficiency work. Taking into account the heat balance between the heat that produced engine, and the heat that is discharged through the cooling system, allowing support optimum coolant temperature liquids, preventing overheating and ensuring stable engine operation.

Also no less it is important to control the temperature of the transmission unit. This stage critical because transmission unit overheating maybe not only to lower efficiency transmission, but also cause mechanical breakdowns. Transmission unit cooling necessary for support stable works transmissions and reductions losses Energy regulation temperatures in the system transmission helps save optimal level efficiency, reducing probability mechanical failures.

No less than the problem of harmful substances is important emissions, especially in conditions modern environmental standards. For machine- tractor units it the question is extremely relevant because wrong level emissions maybe to cause a violation ecological standards and penalties. The system must constantly monitor level emissions, and if he exceeds permissible value, automatically regulate the operation of the unit, reducing power or activating additional filters to reduce pollution surrounding environment [9].

Analysis efficiency the operation of the unit is as follows important stage. For this is calculated coefficient useful actions that allows to estimate how much energy from generations is converted into useful work. Low efficiency maybe to testify to the need technical service or problems with the unit settings. Regular monitoring efficiency helps on time detect decrease productivity and take appropriate measures.

Final the next stage is to identify malfunctions or emergency situations. Since the unit operates in difficult conditions, it is important have a system that allows in time detect overheating or excess emissions. With the help of sensors and controllers, the system must automatically respond to deviations from normal parameters and use measures to prevent serious damage or accidents. This gives opportunity not only save the unit's performance, but also to avoid unnecessary repair costs.

Let's check the algorithm for analysis dependencies temperature and power when working on the mixture biofuels with a content of 5% BP-95%DP, 30% BP-70%DP, 50% BP-50%DP, repeating experiment twice Fig. 2.

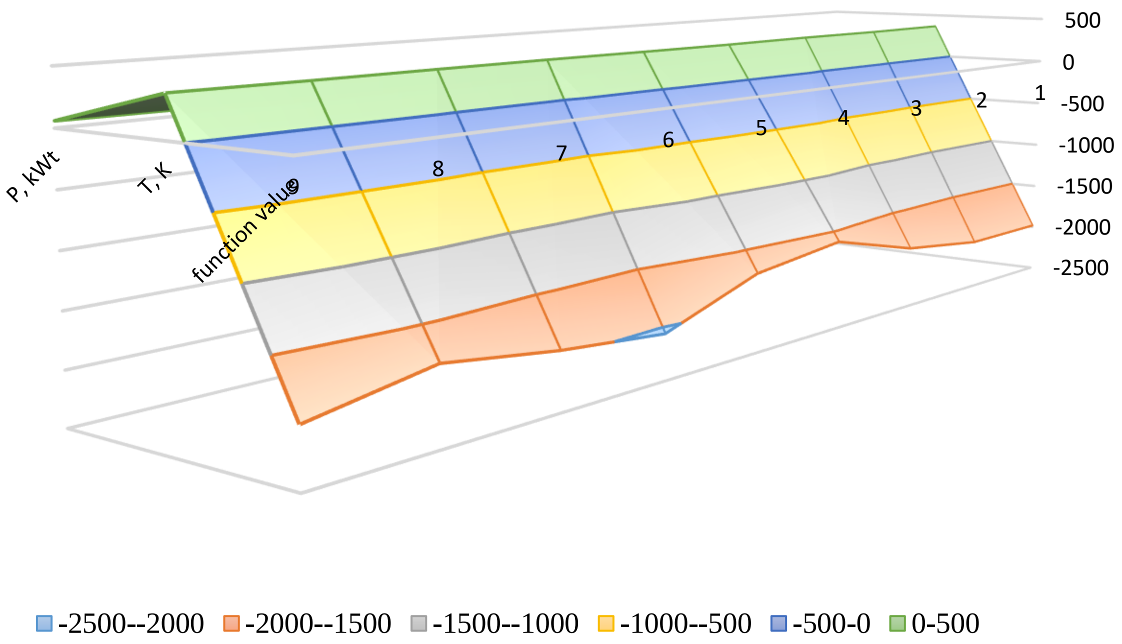

Fig. 2. Surface of the unit's efficiency depending on temperature and power

Negative value function value can to testify that efficiency works decreases, and perhaps also about inefficient consumption energy at certain values power and temperature . In the case of costs biofuels, negative value maybe mean that the system is operating at minimum costs with these parameters.

5. Conclusion

The development and implementation of an algorithm for the functioning of a machine-tractor unit, which is based on careful monitoring and optimization of key parameters, is a necessary condition for ensuring the efficiency, reliability and environmental safety of the equipment. Each of the stages - from calculating power to controlling emissions and temperature conditions - contributes to achieving maximum results with minimal resource consumption, increasing the overall efficiency of the unit. Integration all these factors allows not only save technical serviceability machines, but also to reduce probability emergency situations that maybe much to reduce maintenance and repair costs.

In addition, it is important component this algorithm is a match environmental standards that allows reduce level harmful emissions into the atmosphere. In conditions hard ecological requirements modern world, such attention to conservation surrounding environment is necessary to maintain sustainable development and provision high standards in rural economy and others industries where machine- tractor equipment is used aggregates.

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ОПТИМІЗАЦІЯ ВИТРАТИ БІОПАЛИВА ЗА РАХУНОК РОЗРОБКИ АДАПТИВНОГО АЛГОРИТМУ КЕРУВАННЯ

У статті розглядаються сучасні підходи до підвищення ефективності роботи машинно-тракторних агрегатів шляхом оптимізації витрати палива за допомогою змішувача паливних компонентів. Зростання цін на паливо та посилення екологічних вимог спонукають до пошуку нових технологій, що забезпечують економічну та екологічну експлуатацію сільськогосподарської техніки. Одним із перспективних рішень є використання систем живлення зі змішувачем палива, який дозволяє регулювати співвідношення компонентів паливної суміші в режимі реального часу, враховуючи навантаження на двигун, його швидкісні та температурні режими.

У статті детально аналізується вплив різних параметрів паливної суміші на ефективність роботи двигуна та його економічність. Запропоновано математичну модель процесу змішування палива, що враховує фізико-хімічні властивості компонентів, а також алгоритм керування, який дозволяє адаптивно налаштовувати паливну суміш для досягнення оптимальних показників витрати. Проведено комп'ютерне моделювання роботи двигуна з використанням різних складів паливної суміші, що дозволило оцінити вплив змішувача на динамічні характеристики агрегату та економічність витрати палива.

Результати досліджень демонструють, що використання змішувача палива дозволяє знизити витрати на 10-15% без втрати потужності, зберігаючи при цьому стабільність роботи двигуна. Крім того, вдалося зменшити викиди шкідливих речовин в атмосферу, що сприяє підвищенню екологічності сільськогосподарських робіт. У статті також наведено рекомендації щодо налаштування та експлуатації системи змішування палива для досягнення максимальної ефективності.

Запропонований підхід може бути корисним для інженерів, які займаються розробкою паливних систем, а також для аграріїв, що прагнуть знизити експлуатаційні витрати. Отримані результати сприяють подальшому розвитку енергоефективних технологій у сільськогосподарському машинобудуванні.

Ключові слова: *оптимізація витрати палива, машинно-тракторний агрегат, змішувач палива, паливна система, економічність витрати палива, алгоритм керування, паливна суміш, енергоефективність, сільськогосподарська техніка.*
Ф. 1. Рис. 2. Табл. 1. Літ. 9.

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