Automated assessment system of energy parameters of the tractor fleet

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Abstract. The expediency of operational control of the energy parameters of the agricultural enterprise's MTP under operating conditions is shown, which allows timely repair and maintenance measures to reduce power losses. An algorithm for automating the monitoring of energy indicators of tractor engines has been developed, including the main technological procedures for each unit of household equipment. An automated system has been formed based on the proposed algorithm and the diagnostic device for energy monitoring of the tractor fleet of the agricultural enterprise developed at SibFTI. The issues of practical application of the system in the agricultural enterprise are considered.

1. Introduction
Losses of tractor power during agricultural work due to wear of parts, violations of adjustments and settings of mechanisms and systems significantly reduce the efficiency and competitiveness of the farm. The lack of control over the parameters of the technical condition of internal combustion engines (ICE) of the machine and tractor fleet (MTP) (power, fuel consumption – without special means) leads to the use of tractors with excessive fuel consumption due to loss of traction properties. At the same time, while ensuring permanent determine the actual status of the machine and tractor unit can reveal hidden reserves of power within 6 – 15.6 %, fuel consumption– 12-18.7 % [1, 2].

This gives reason to solve the problem of maintaining the necessary level of energy field work due to the rapid assessment of the energy parameters of each tractor tractor fleet (ICC), some farms and timely adoption of the control actions, which will reduce the cost and complexity of re-monten-maintenance works.

The existing method of energy assessment of agricultural machinery according to GOST 52777 provides bench tests of engines, which practically excludes its use in operational conditions. Therefore, it is advisable to use the well-known and widely used dynamic method of diagnostics of tractor engines [3]. A feature of the method is the need to obtain and process large amounts of data from physical workflows. The successful solution of this problem is facilitated by the significant development of digital technologies and electronic means in the system of maintenance and repair of automotive and combine machinery [4, 5].

Proceeding from this, in order to automate the process of energy assessment, it is advisable to use information digital technologies to implement complex algorithms for computer modeling of transients, calculation of speed characteristics and energy parameters of the internal combustion engine. In addition, it is important to solve the problem of information support of the technological process of assessing the power of the internal combustion engine, providing data registration and processing, as well as visualization of the results based on a user-friendly interface.
The purpose of the study is to develop an automated system for energy monitoring of the tractor fleet of an agricultural enterprise based on the dynamic method of diagnosis of internal combustion engines using modern information technologies for data collection and processing.

2. Research methods
The methodological basis of the research is a computer model of internal combustion engine dynamics, developed taking into account the long-term experience of developers [6]. It takes into account the non-linearity and non-stationarity of individual links, the influence of changes in a number of important parameters of individual units and systems and the manifestation of significant non-linearities and other deviations on the output processes of the engine as a function of time, angular displacement, speed and load modes. At the same time, time, frequency and statistical characteristics of processes, their partial and integral indicators are calculated. It is applicable both in bench research tests and in operational conditions.

To determine the power of the internal combustion engine, the angular acceleration of the crankshaft is calculated using the dynamic method \( \varepsilon \). In stationary mode, due to the uneven rotation of the crankshaft and in the free acceleration mode (at load moment \( M_{\text{load}} = 0 \)), the angular acceleration of the crankshaft is determined by the dependence:

\[
\varepsilon = \frac{1}{J_d} \left( M_i - \omega \frac{dJ_d}{d\varphi} - M_m - M_{\text{w}} \right) = \frac{1}{J_d} \left( M_i^c + M_i^g - M_m - M_{\text{w}} \right)
\]

where \( J_d = J_d(\varphi) \) - is the reduced moment of inertia of the internal combustion engine and load masses (when the load moment \( M_{\text{load}} = 0 \) is the internal combustion engine’s own moment of inertia brought to the crankshaft); \( \omega \) - is the angular velocity of the crankshaft (rotation speed \( n = \frac{1}{2\pi} \int \omega d\varphi \)); \( \varphi \) - is the angle of rotation of the crankshaft (PCV); \( M_i = M_i(\omega, \psi, \varphi) = M_i^c + M_i^g \) - the indicator moment of the engine (\( \psi \) - is the position of the fuel supply body); \( M_i^c = \sum l_i M_i^{c(k)} \) and \( M_i^g = \sum l_i M_i^{g(k)} \) - compression and gas components of the indicator moment; \( M_{\text{m}}^c \) and \( M_{\text{m}}^g \) - compression and gas components of one cylinder; \( i_n \) - the number of cylinders:

\[
M_{\text{m}} = M_{\text{m}}(\omega, \varphi) = M_{\text{m}}^{\text{inc}}(\varphi - \xi_m) + M_{\text{m}}^{\text{inc}} = \omega^2 \frac{dJ_d}{d\varphi} - \text{the inertial component of the torque-the one containing the regular component caused by unbalanced inertial forces; } M_{\text{m}} = M_{\text{m}}(\omega, \varphi) - \text{the moment of internal losses (mainly friction). If we ensure the separation of the full acceleration of the crankshaft of the internal combustion engine into separate components for each of the cylinders both in the stationary mode of full load and in acceleration, then they can be used to assess the unevenness of the cylinders and the intra-cycle unevenness of the internal combustion engine.}

When diagnosing the state of the internal combustion engine, signals of physical processes are used that characterize the operation of the engine. After measuring and preprocessing the signals from the sensors, information processing is performed. The randomness of the processes of fuel supply and combustion from cycle to cycle, as well as friction processes in the interfaces of the internal combustion engine cause random deviations of the angular velocity and acceleration of the crankshaft \( \omega(t) \) and \( \varepsilon(t) \) from their average values. This leads to the need to consider the measured processes as an additive combination of a useful informative (diagnostic) process and interference. To determine the parameters when justifying the method, it is advisable to use well-known probabilistic methods of signal analysis, statistical methods of optimal signal processing against the background of interference [7].
An important aspect of the development of research is the need to take into account the fact that modern automotive engines are equipped with an electronic control system that provides the necessary algorithm for controlling engine operating modes based on the characteristics of the measured values of engine parameters. Hence, the principle of creating diagnostic systems using the tractor's on-board network is obvious – this is the diagnosis by various analytical methods of the measured processes not only from special installed sensors of the physical processes of the internal combustion engine (for example, sensors of the angular position of the crankshaft), but also using signals determined by the standard protocol of means of communication from sensors of the electronic control system [8].

3. Research results

An algorithm for automating the monitoring of energy indicators of the machine and tractor fleet of an agricultural enterprise is substantiated and developed, the scheme of which is shown in Figure 1.

The algorithm provides procedures for entering initial (passport) data for each unit of the tractor fleet of a separate agricultural enterprise, evaluating the current energy performance of each tractor using a tool, forming databases of current and passport values, as well as the results of deviations and recommendations.

A diagnostic device developed at SibFTI was used as a tool for automating the assessment of the energy parameters of the internal combustion engine [8, 9]. Its block diagram is shown in Figure 2.

Main functions: measurement of the crankshaft rotation speed under dynamic effects on the internal combustion engine; synchronization of measurements with monitoring and ensuring the necessary number of full-fledged single test effects in the test cycle; construction of a high-speed dynamic characteristic of the internal combustion engine in power and torque; calculation of a complex of diagnostic energy characteristics according to speed characteristics similar to bench tests.

When registering data simultaneously with the operation of the software, the mechanic performs the procedure of multiple tests of the impact on the internal combustion engine (acceleration-run-out). The evaluation of the power of the internal combustion engine is carried out in real time according to the speed characteristics by the method of discrete differentiation of time interval data.

Information support of the operations of the technological process of the internal combustion engine energy assessment is provided using a user-friendly interface, providing the user with the opportunity, among others, to directly control the process of submitting test effects, data registration.

An experimental test of the automated system in the conditions of a farming enterprise was carried out on the example of FSUE "Elite" of the Novosibirsk region [10]. The tests were carried out during field work from May to October with a frequency of 2-4 times a week on 5 tractors of domestic production equipped with sensors for the angle of rotation of the crankshaft. The values of the power of the internal combustion engine are estimated and their changes over time are established both for each tractor and for the control group of tractors as a whole:

- for the MTZ-82 tractor group, during the test period, the power value varied within 5-10% of the average spread from measurement to measurement;
- MTZ-1221 in 2015 revealed a decrease in capacity by 7.9% of the nominal, and in 2016 a decrease in capacity to 11.2%, which is 3.3% higher compared to 2015. A malfunction of the pump regulator has been detected;
- a power drop (up to 20%) was observed on the K-700A over the entire observation period.

As a result of the research, a digital technology of energy monitoring of the tractor fleet of an agricultural enterprise has been developed and methodological recommendations for the diagnosis of internal combustion engines of energy-saturated equipment by the dynamic method have been prepared [11, 12]. The technology is designed to obtain operational data on the energy parameters of MTP tractor engines of the economy, contributing to the timely adoption of control actions.

In addition, knowing the actual energy potential of the farm at the current time and taking into account the experimentally justified dynamics of its change, it is possible to ensure objective planning of the timing and volume of field work, which contributes to increasing the efficiency of the use of equipment and reducing the cost of production.
Input of initial data:
1. Brand and state number of the tractor (power equipment)
2. Make/type of engine
3. Effective power, kW
4. Effective torque, N*m
5. Rated speed, 1/min
6. Maximum speed of rotation H.H., 1/min
7. Minimum rotation speed of H.H., 1/min
8. Rotation speed at maximum effective torque, 1/min

Is the data entry correct?

Database of internal combustion engine passport values

Receiving data from internal combustion engine sensors (standard or installed). Measurement of angular velocity.

Determination of angular acceleration of the crankshaft of the internal combustion engine of a given tractor (power equipment)

Calculation of internal combustion engine parameters: Effective power (kW), Effective torque (N*m), Moment of resistance (N*m), Nominal speed (1/min), Maximum rotation speed (1/min), Minimum rotation speed (1/min), Rotation speed at maximum effective torque (1/min), Conditional mechanical efficiency (%). The degree of irregularity of the speed of the regulator, the coefficient of torque reserve

Are all tractors (power equipment) rated?

Output

Figure 1. Scheme of the MTP energy indicators monitoring algorithm
**Conclusions**

The expediency of operational control of the energy parameters of the internal combustion engine of an agricultural enterprise under operating conditions is shown, which allows timely repair and maintenance measures to reduce power losses.

An algorithm for automating the monitoring of energy indicators of tractor engines has been developed, which includes the main technological procedures for each unit of household equipment - entering passport data, measuring work processes during dynamic test exposure, and calculating parameters.

An automated system has been formed based on the proposed algorithm and a diagnostic device for energy monitoring of the tractor fleet of an agricultural enterprise developed in SibFTI during field work.

An experimental test in production conditions confirmed the possibility of monitoring the power parameters of the internal combustion engine during field work. The analysis of the data obtained allowed the farm to take operational repair and adjustment control actions, prevent fuel overspending and increase costs, thereby increasing the efficiency of agricultural production.

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