EXAMINATION OF THE SYSTEM OF CONTINUOUS DIAGNOSIS AND FORECASTING OF MECHANICAL CONDITION OF TRACTORS AND OTHER FARM MACHINERY

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The paper presents an experimental system of continuous diagnosis and forecasting of the technical condition of tractors and other farm machinery. The system has both advantages and disadvantages. The experiments proved that the imprecisions of the existing Russian domestic sensors and actuating devices are several times higher than the permissible errors of engine parameters and its process conditions, which were determined based on the analysis of the engine adjusting characteristics. The system we offer allows to expand significantly the possibilities of the use of the agricultural aggregates, machines and implements and to reduce the down and repair time. The existing microprocessor side system significantly simplifies the synthesis of the proposed system and expands the technological capabilities. It allows to make automatic diagnosis of the technical condition of the machine-tractor aggregate (MTA) and makes it possible to obtain information on the need for motor maintenance (MM) if necessary. The option of voice information makes the operator work easier and thereby increases the efficiency of MTA field work.

Key words: diagnostic, prediction, indication, controller, telematics.

INTRODUCTION

Constant modernization and upgrade of the technological means are a must for efficient development of the agricultural production [1]. The analysis of scientific and technical publications showed [1-19] that mechatronic (telematic) side systems are becoming the basis of technical progress in agricultural engineering. At the same time, diagnostics of their technical condition is a standard procedure for all microprocessor systems. Thus, the level of technological infrastructure of agricultural production is determined by the presence of mechatronic control systems and performance control of tractors and other agricultural machinery. Mechatronic systems include: By dividing mechatronic systems into the above mentioned components, we can speak about a three-pronged continuous functionally-complete system. Its power unit consists of rather simple mechanical assemblies, which act as performers in this system. The informative part is embedded into the executable software and recorded in microprocessors making a whole of the entire MTA system [5].

The functions of the operator (tractor-driver) in this system are limited. These functions include starting the engine, controlling the operation of all systems, driving and stopping the unit, interfering with the operation of the automatic control system (ACS) in extreme situations, and stopping the engine. In some cases, the operator controls directly the MTA operating mechanisms by signals from sensors or control elements on the information display. However, only some systems can perform self-control. Thus, for example, Motronic system by Bosch can self-diagnose ignition and fuel injection [4]. The integrated system of "Hardware-in-the-Loop" type for the agricultural tractors [15] allows to determine the faults and display the error codes during scanning. Unlike tractors, almost all modern cars have a built-in digital Controller Area Network (CAN) interface for data transmission [4]. MTA differ from cars in the principle of their operation and diagnosis.

Having analyzed the results of works in this area [4-19], we have systematized the requirements for diagnostic systems:

First, the system shall ensure the warning of the operator and the owner of the management object about the system faults or the diagnostic system itself using the indicators, displays and audio warning unit as well as book an appointment at the service center.

Second, the system shall ensure the access to the technical information and its storage, in particular, warning information in the control panel and data on certain faults. Herewith, the data on the engine's operating conditions will be saved during the fault's detection. The type and completeness of the information are subject to standards SAE J1978, SAE J1979 and SAE J2205. The data, stored in the memory of the self-diagnostic system is transferred to the failure-detecting stand, equipped with display through GSM channel. Afterwards, the personnel shall contact via the Internet the central server, detecting the fault and suggesting the algorithm of its remedy in a form of the step-by-step instructions. Communication protocols are specified in standards ISO 9141-3 and ISO 14230-4 [4].
Third, the tractors and agricultural machines modern designs shall be equipped with the autonomous trouble-shooting systems. Such systems allow to significantly expand the possibilities of the various agricultural aggregates, machines and implements use. For example, continuous monitoring of the technical condition of the MTA ensures timely maintenance, which increases the level of operational reliability and machine efficiency. The micro-processing control can widen significantly the technological possibilities, and the side microprocessor system ensures the automated diagnostic of the MTA technical state. It provides the information on the required technical maintenance (TM), if necessary. The audio warning option facilitates the operator’s work, thus improving the operation of the MTA field works.

Therefore, the work is aimed at the study of the system and interrelations during the implementation of the remote continuous diagnostic and work prediction of the autotractor and agricultural machinery systems.

The practical use of the study results optimizes the MTA diagnostic process and improves operating reliability of its equipment.

**MATERIALS AND METHODS**

The subject of the study is the remote continuous diagnostic and work prediction system, which ensures the technical information exchange, coming from the available MTA sensors in the process of the movement with the changing pulling load. As additional sensors, it is recommended to use the ESM-27E oil quality sensor and the residual brake lining thickness sensor of type Z-TP1 (Figure 1, Table 1). The information comes from the system to the central diagnostic server, which determines the fault and suggests the variants of their remedy in a form of a step-by-step instructions for the management subject, individually for the personnel of the workshop and in software in a form of prediction of the faults and required repair operations. The object study was performed under the field operating conditions using the simulation mode of the complicated technological processes, using the queuing theory and methods of observation and experiment.

The mathematic processing of the experimental data was performed using the software with three approaches: using the dispersion analysis, ensuring the significance of differences between the groups by each variable; using the cluster analysis, related to the division into homogeneous groups within the whole selection; using Data Mining analysis, which diagnoses logical regularities.

The reliability of the results and conclusions of the research was provided by sampling, the use of mathematical and statistical methods, and a meaningful analysis of the revealed factual material.

Scientific novelty is a possibility of remote continuous diagnostic, faults prediction and repair planning of domestic automotive and agricultural equipment in real time.

Results of the experimental studies and their analysis. Experimental MTA was equipped with tractor Belarus 1523 with 155 h.f. engine and shallow plough LDG-5 with disc harrow BDN-3 (Figure 2).

Let us consider the operation of this aggregate as the dynamic system under the environmental effect $F_i(t)$ (Figure 3).

In this case the management subject - a tractor operator, accepts only the output signals $x_i(t)$ from the tractor and implements reading instruments (engine crankshaft...
Table 1: Sensors of the MTA operation

| Used sensors | Diagnostic parameters |
|--------------|-----------------------|
| of the tractor engine and transmission |             |
| • fuel consumption DFM Contoil 8 D / S; | \( g_c \), \( N_c \), \( M_c \) | Respectively specific engine fuel consumption, engine power and torque |
| • inductive crankshaft PRAVT 233847* positions; | \( \omega \) | Engine speed |
| • fuel control lever 6PV 010 946-001 positions; | \( K_m \) | Engine lugdown and recovery by torque |
| • vibrations BD06A; | \( \varepsilon_m \) | Engine load ratio |
| • oils quality ECM-27 E | \( n_{\omega} \), \( n_\omega \) | Effective engine efficiency, transmission efficiency |
| of the whole MTA |             |
| • speedMTZ-80, 82AP70.3843-01; | \( v, n_v \) | Effective velocity and driven wheels rotation frequency |
| • forcesDU-03-60 TYPB*; | \( P_z \) | Pulling force |
| • torque M425; | \( M_z \) | PTO shaft torque |
| • end-effector positions Z-TP1-P06; | \( H, B_p \) | Operating depth and aggregate's operating width |
| • fuel consumption DFM Contoil 6 D/S. | \( \delta, P_o, I, \lambda \) | Respectively slipping and additional loading for trailing weight increase and tractor trailing weight percentage, used for pulling force generation |
| of separate aggregate assemblies |             |
| • pressure, type MD 50...100, TPMS Hid1100*; | \( p_x, p_o, p_c \) | Respectively pressure in the hydraulic system (oil), lubricating system (oil), cooling (antifreeze solution), tires (air). |
| • temperature, type TP*; | \( l_x, t_x, t_o \) | Respectively temperature in the lubricating, cooling and actuating fluid systems |
| • general purpose lambda probe Is001-2*; | \( h_x \) | Actuating fluids level |
| • positions Z-RFC-P01; | \( \gamma \) | Emissions oxygen content |
| • indicating I-TYPE 2018; | \( \hat{\delta}_b \) | Brake lining wear |
| • pressure F-TYPE 2018, MD100. | \( p_z \) | Engine cylinder pressure |
| | \( p_i \) | Injection pressure of engine fuel nozzles |

*installed on the aggregate by the manufacturer.

speed, travel velocity, cooling system fluid temperature, oils pressure, operating depth etc.), providing feedback and affecting the controls \( z(t) \). At the same time, he constantly controls the technological process (during dehulling, mainly absence of the fail places and laps), ensuring the required specified parameters \( z(t) \) and aggregate safety during operation.

During the experiments on functions a tractor operator had to make decisions on the control activity such as direction change, fuel feeding or gearshift, to solve the off-schedule tasks, taking into account speed rate maintenance of the specified technology (12 km/h) as well as its deviations and external factors. The shallow plough design presupposed the lead angle changes within 0-30° using the hydraulic system.

As a result, it appeared that a human could not always be able to process completely the interrelated information flow and make the most adequate solution during the operation because of his limited physiological capabilities. The frequency of deviations from the width of the grasp per shift with a fixed impinging angle was up to 3 times per hour by the end of the working shift. During the tractor operator's additional load, when he had to record the engine technical indicators once an hour, this indicator increased up to 5.
In order to relieve the tractor operator during the tests the tractor was equipped with a number of the non-standard sensors (they are shown in Table 1 without * sign). Moreover, scheme 3 was used to assemble special system. The suggested control, side diagnostic and fault prediction system (CDS) provided the feedback $y_i(t)$. This CDS variant accepted the output signals $y_i(t)$, transformed them into a digital form, processed according to the set algorithm [12] under the specified parameters $z_i(t)$, compared the output signals with the required for the drawing machine and implements and sent the control signal to the actuating mechanisms $z_{i1}(t)$, triggering the tractor’s operating mechanisms, determined the error and, if necessary, it also informed the tractor operator, service or agricultural departments on the parameters to be changed, on the planned spares replacement or adjustment parameters.

The principal elements of the suggested system [2] were the electronic control unit (as in Figure 5: microprocessor assembly with communications terminal A, satellite antenna B, wire harness C and GPS antenna D to transfer the data to the server using the wireless network) and the sensors, connected to the transmission data of attire, running gear and assemblies (Figure 6), allowing to perform independently the MTA technical state continuous control.

The microprocessor assembly is made based on microprocessor SAB100C917A by SIEMENS; it has 25 Kbyte core-memory (RAM) and 2018 Kbyte read-only memory (ROM) 2018.

The system microprocessor assembly is based on the diagnostic and prediction program, used to determine the belongings of the output control and technological parameters-adapter $x_i$ measured values to the set required intervals, limited by minimum $x_{imin}$ and maximum $x_{imax}$ values

$$ xi \rightarrow [y_{imin}, y_{imax}], i=1, ..., n $$

If value $x_i$ was within the specified accepted interval, the system aggregate operation (assembly, spare part) is considered possible and stable. Otherwise, the CDBS sends a control signal to switch the system into a stable condition and records the error if the respond is unsatisfactory. After that the error is analyzed in order to choose further actions.

Thus, we showed function (1) as an interval pattern
Where $\Delta x$ - acceptable deviation of $x_i$ parameter from optimal value $x_i^{opt}$.

We split control operation parameters (markers) $x_i$ into energetic and operating for the sake of convenience (Table 1). The first group includes the values, which depend on the fuel injected to the cylinder, i.e. effective power $P_{е}^e$ and specific effective fuel consumption $g_{е}^e$, torque $М_{е}$, adjustability factor $k_{м}$ and engine crankshaft rotation frequency $\omega_{н}$. These parameters were adjusted on the stands before the technological operation. The final operating weight $m_{од}$ of the tractor with ballast was 6260 kg. This value did not change during the operation.

The operating parameters characterizing technical and economic aggregate indicators during the working stroke were measured and controlled. Load ratio by torque $\varepsilon_{m} = М_{к}/М_{н}$ was used as the resulting indicator, which characterizes the loading mode [11].

The forecast for the engine working parameters was made based on the separate assemblies operating markers, and the input indicators - under random variables, as they comply with a normal probability law. Thus, we considered the tractor and working machine parameters, adjustable during the working stroke and aggregate technical and economic indicators as the random variables.

Let us show the whole data flow within system MTA - CDS as a multiple dynamic system being a part of the aggregate (Figure 6).

It was convenient to split the system in four device groups in accordance with the specified structural scheme: engine, transmission, travel system and implement. The experiments proved that the imprecisions of the existing Russian domestic sensors and actuating devices are several times higher than the permissible errors of engine parameters and its process conditions, which were determined based on the analysis of the engine adjusting characteristics.

In order to describe each group functioning for adaptation, we arrange the output parameters-markers dependencies on the input. Thus, the crank shaft rotation frequency $\omega_{н}$, which depends on moment of resistance $М_{с} = М_{е}$, will be used as the output parameter-marker at the established energetic tractor parameters ($N_{е} = 116 \, kWm$) and engine characteristic ($М_{е} = 603 \, Nm$, $k_{м} = 16,5\%$, $n = 2100$). The below mentioned dependency can be used to describe this equipment group functioning when using the tractor in the traction mode.

The state of this group can be assessed using the following sensors parameters $p_{оп}, t_{в}, p_{о}, t_{о}, h_{o}, \gamma$ (See Table 1). Additional electrical oil change sensor ECM-27 E was implemented to control the motor oil quality (Table 1). The active level was programmed before connecting the sensor to the controller. After that, the "alarm zone boundaries" were set so that the input voltage when inactive was in the middle of the alarm zone, and in case of a stub closure or its break - overran it. Input 5 V voltage is the maximum level 100%.
The tractor mechanical transmission transforms parameter $\omega$ into tractor theoretical velocity $V_T$ (drive wheels speed $\omega_w$), therefore the second group functioning at the input parameter - drive wheels tangential traction $P_T$, is estimated, using the following expressions:

$$
\begin{align*}
V_m &= \pi \times n \times \frac{r_w}{30} \times i_{mp} \\
P_T &= M_c \times i_{tr} \times \eta_T \times i_{r_d}
\end{align*}
$$

Where $i_{mp}$ - transmission gear ratio.

Interrelation of output $V_m$ and input $P_T$ parameters is defined based on the functional condition at $r_d=\text{const}$, $i_{dem}=i_{tr}$

$$
V_m = \pi \times n \times M_c \times \eta_{mp} \times 30 \times \frac{P_T}{30} \times \frac{1}{r_d}
$$

Transmission state and operation prediction can be assessed based on values $P_T$, $i_{tr}$. We diagnosed the state of assembly part sand planned the repair based on these sensors readings together with the oil condition sensor, similar to the sensor, described below. Before the experiment we filled the engine lubricating system with motor oil M102, which resulted in the pressure reduction during the experiments from 7 to 4.5 bar at engine speed 2100 min$^{-1}$.

Pulling force $P_k$ and tractor rolling resistance $P_f=m_f \cdot g \cdot f$ were the external influences on the third experiment group. The output parameter is actual tractor velocity $V=V_m \times (1-\delta)$, which at the same time is the principal tractional aggregate parameter-marker. Its relationship with the input and set parameters is determined by the equations system:

$$
\begin{align*}
P_K &= P_{KP} + P_f \\
V &= \frac{\varepsilon_N \cdot N_c \cdot n_{mp} \cdot (1-\delta)}{P_{KP} + P_f}
\end{align*}
$$

Parameters optimization criterion $(n, M_c, i_{tr})$ for determination of energetic (Ne) and pulling-adhesion tractor parameters $(\eta_{tr}, \delta_{mp})$, known aggregate pulling force characteristics $(P_{rock}, \omega_{prow})$ and operation speed values($V_{avg} \pm \Delta V$) change intervals can be presented as a minimizing function.

$$
P_f = \frac{\pi \cdot M_c \cdot \omega_H}{30 \cdot N_e - 1} + \frac{\pi \cdot \omega_H \cdot \varepsilon_N}{30 \cdot V_H \cdot i_K \cdot \varepsilon_M - 1} + \frac{P_{KP} \cdot m_f \cdot g \cdot f}{\eta_{mp} \cdot \varepsilon_N \cdot M_H \cdot i_f - 1} \rightarrow \text{min}
$$

MTA operating efficiency with the set parameters of specific pulling force, in our case, was determined by net performance indicators $W$ (m$^3$/s), specific energy consumption $E_i$ (kJ/m$^3$) and per hectare fuel consumption $g_{sh}$ (kg/he):

$$
\begin{align*}
W &= \varepsilon_N \cdot N_c \cdot \eta_{mp} \cdot K_e \cdot (1 + \Delta K(V_H^2 - V_0^2)) \rightarrow \text{max} \\
E_i &= \frac{E_i}{W} \rightarrow \text{min}, \\
g_{sh} &= \frac{2.77 \cdot G_k}{W} \rightarrow \text{min}
\end{align*}
$$

If these parameters deviate from the limit values, the on-board continuous diagnostic system provides a control signal $C_{i}$ to correct the system and transfer it to a stable state. In case of repeated unsatisfactory response, an error is indicated, which serves as the basis for making further decisions on the need for voice dialing, SMS, communication with the machine operator via an external microphone, including GPS, auto tracking, maintenance or repair.

The experiments revealed unreasonable fault alarms appearance. Therefore, the self-diagnostic algorithm and emergency operation mode were introduced in case of sensors breakdown. Actuators control output keys were equipped with short-circuit protection.

The diagnostic subsystem was implemented in the electronic control unit software, which allowed to determine current faults of the system and unit and record them. The errors received by the electronic unit during the experiments were transferred to the controller for processing and further transmitting to the service company diagnostic station (Figure 7). The remote diagnostic scheme was as follows:

1. To check operation of the on-board diagnostic system and diagnostic chain.
2. To determine the fault codes.
3. To transfer the faults, affecting MTA operation quality to the service center diagnostic station.
This study examined the sequencing of the vehicles in service through the diagnostic stations and technical maintenance. Such a system can be considered as a two-phase system with stand-by, which receives almost unlimited demands deluge. As long as different service departments can maintain various assemblies and aggregates, the principal simulation and optimization task is to receive such summary regularities and results, which can be applied to any vehicle type under any conditions.

In order to determine technical indicators of the two-phase diagnostic and technical maintenance system functioning we use the indicators of the number of traction vehicles, which are in the first phase (under diagnostic) \( m_{01} \) and in the second phase (under technical maintenance) \( m_{02} \), as well as the respective down-time probabilities of the mentioned phases \( P_{01} \) and \( P_{02} \), depending on ratio \( \alpha_{1} = \lambda / \mu_{1} \) and \( \alpha_{2} = \lambda / \mu_{2} \) between demands density \( \lambda \) and maintenance intervals \( \mu_{1} \) and \( \mu_{2} \) in each phase.

The summary dependency schedule in the diagnostic phase \( m_{01} \) and technical maintenance phase \( m_{02} \) respectively on \( \alpha_{1} \) and \( \alpha_{2} \) is shown in Figure 8. According to the schedule value \( m_{01} \) is determined using dependence on \( \alpha_{1} \) and \( m_{02} \) using dependence on \( \alpha_{2} \). Values \( m_{01} \) and \( m_{02} \) with respective upturn \( \alpha_{1} \) and \( \alpha_{2} \) increase by hyperbolic dependence. Using acceptable values \( m_{01} \) and \( m_{02} \) and taking into account the production premises it is possible to determine respective values \( \alpha_{1} \) and \( \alpha_{2} \). Required maintenance intervals \( \mu_{01} = \lambda / \alpha_{1} \) and \( \mu_{02} = \lambda / \alpha_{2} \) can be determined using the set demands deluge \( \lambda \).

\[ m_{01} = \frac{\alpha_{1}}{1 - \alpha_{1}} \]
\[ m_{02} = \frac{\alpha_{2}}{1 - \alpha_{2}} \]
Many scientists proved with the experiments \([1-5]\), that the density considered Poisson. Based on this we determine faults using known values mine the respective probabilities of diagnostic station \(\alpha\) and technical maintenance \(\mu\). For example, in the first phase \((m_{o1}=2)\), and three - in the second \((m_{o2}=3)\), then \(\alpha_{o1}=0.63, \alpha_{o2}=0.72\) in Figure 7 schedule. Herewith, maintenance intervals should be \(\mu_{o1}=1.9\) and \(\mu_{o2}=1.67\). The number of stations, diagnostic specialists and fixers can be determined using values \(\mu_{o1}\) and \(\mu_{o2}\).

Using known values \(\alpha\) and \(\mu\), makes it possible to determine the respective probabilities of diagnostic station \(P_{o1}\) and technical maintenance \(P_{o2}\), downtime (Figure 8). For example, in the first case at \(\alpha_{o1}=\alpha_{o2}=0.65\), we get \(P_{o1}=0.277\), as shown by arrows in Figure 8. At \(\alpha_{o1}=0.65, \alpha_{o2}=0.72\) in order to determine \(P_{o1}\) value \(\alpha_{o1}\) is laid along the horizontal axis, and \(\alpha_{o2}\) - on the respective half ray. In this case we get \(P_{o1}=0.26\). Similarly, when determining \(P_{o2}\), we lay value \(\alpha_{o2}=0.72\) according to the horizontal axis, and \(\alpha_{o1}=0.65\) - according to the half ray. In this case \(P_{o2}=0.188\) as shown by the dashed lines.

The system was equipped with the interface, specifying the aggregate location on the map, faults detection, operation time and required technical maintenance in order to facilitate identification and search(Figure 9).

The experimental study showed that the demand density for elimination of the technical faults can exceed possible number of the vehicles repaired in the service center (repair shop). By accepting the technical faults flow as distribution \([6]\), it was determined that probability \(P_k(t)\) of demands receipt \(t\) for period \(t\) is computed using Poisson formula.

\[
P_k(t) = \frac{(\lambda t)^k}{k!} \cdot e^{-\lambda t}
\]

Many scientists proved with the experiments \([1-5]\), that the faults flow of the tractors with adequate accuracy could be considered Poisson. Based on this we determine faults density \(\lambda\) using equation

\[
\lambda = \frac{1}{\tau_{otk}}
\]

where \(\tau_{otk}\) - average time between faults (time between faults), \(1/\text{h}\).

It is supposed that servicing of each demand is performed by one stationary means, thus the interval of the respective maintenance is computed by equation

\[
\mu = \frac{1}{\tau_{o6}}
\]

where \(\tau_{o6}\) - average duration of one fault elimination, \(\text{h}\).

Due to the increase in the duration of the fault elimination and in the failure density, a queue of waiting vehicles is formed. Thus, the flow should be reallocated to other services using a computer program.

The experiment showed that the use of the divided method, when reserving separate machines and aggregates elements, the downtime reduces to 19%. It is possible to order reserving with whole or fractional multiplicity, depending on the quantitative ratio between the main and reserve elements or complete aggregates. If any reserve element or aggregate can replace the faulty principal, then it is considered a reserving with roving reservation. In this case, downtime reduces by another 5%. During the experiments we offered to implement a probability of hot, light and cold reservation in the program.

This scheme implementation is an improved advanced analogue of the equipment technical maintenance (shown in red in Figure 10 for comparison) and current repair schedule preventive scheme.

When introducing the continuous diagnostic system (CDS) we used the feedback in order to adjust the engine operation in real time. It allowed us to monitor continuously the sensors readings and forecast in time the need for repair. Indirect indicators diagnostic (at temperature and exhaust gas composition, vibration during operation) allowed to widen the number of the diagnosed parameters, including for conditions determination of the mechanical compo-
The repair warning works in the following way: the information is sent from the machine to the management subject model through GPS channel, and then it is stored and processed.

In case the repair is required, the management subject model makes a decision and informs the service company (SC) on the approximate date of equipment arrival for repair and its replacement, if necessary.

Usually, only a manufacturer or a dealer company have access to such works. Herewith, technical maintenance is a preventive measure, comprising a number of works, aimed at faults prevention, ensuring full operational capability of the vehicle aggregate, assembly or system. Technical maintenance shall be performed in a planned manner through certain runs or a certain time of vehicle operation, avoiding downtime. When using a nominal scheme, a car or a tractor with broken aggregates, assemblies, systems and parts which can threaten traffic security, is not allowed to work and is idle. In this situation servicing is provided by the subject of management itself (a tractor-driver, figure 1 and 9) usually according to working hours.

The proposed system involves sending a message to the machine servicer phone before the shift starts, indicating only the required technical maintenance per shift and notifying autonomously the service company of the expected breakdown. The service company analysts shall make a final decision.

Statistical data processing was performed by regression

Figure 10: Continuous diagnostic system flow diagram MTA-CDS-SC
analysis of functional dependencies. Mathematical analysis gave the following results for the formation of regression equations:

- multiple regression coefficient \( R = 0.9998971 \);
- Fisher's criterion \( F = 390.2639 \);

Data evaluating criteria during remote monitoring are compared with cloud data that is slightly different from the built-in critical values, which are used by the customer’s management system.

The data coming from a particular machine are compared with a huge database of the machinery of this class, which allows to use all the experience available to the system, and anticipating the tendency to deviate from a particular parameter, in a timely manner to exclude serious damage before it creates an emergency situation or an emergency equipment stopping.

The economic effect estimation due to the project proposals implementation was made on the difference of the total reduced costs for a comparable one-time scope of work. The economic effect due to the project proposals implementation was more than 5%.

**CONCLUSIONS**

The structure of the technical state and fault prediction continuous diagnostic system for tractor and agricultural equipment include four groups of interrelated, speed, load and pulling-adhesive parameters-markers, ensuring effective tractor operation as part of MTA. The use of MTA systems remote diagnostic and self-diagnostic helps the management subject to speed up the diagnostic, narrowing the field of possible malfunctions and reduce down time. It is established that creation of a device for remote diagnosis of traction vehicle equipment by means of telecommunication means of GSM standard eliminates the waiting time for the vehicle servicing and provides a predetermined speed, load, thermal test mode in real operating conditions for performing quality diagnosis.

The program algorithm for workflow parameters measuring should compensate for the transformation errors based on the assumption that they are both systematic and random. As for the repair shop we received summary optimal resource-saving combinations between demands density \( \lambda \) and their maintenance interval \( \mu \) over the entire possible range of their change \( \lambda_{\text{opt}} = 0 \ldots 12 \) and \( \mu_{\text{opt}} = 0 \ldots 11 \). Received values \( \lambda_{\text{opt}} \) and \( \mu_{\text{opt}} \) allow to ground the optimal resource-saving parameters of the respective service systems under production. The practical application of the obtained general results of the study provides a significant increase in the efficiency of service stations specializing in machinery production and maintenance.

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