Practical implementation of research on the introduction of on-board meters-indicators for monitoring the technical condition of tractors

M. Kostomakhin[1*], *N.* Kostomakhin[2], *N.* Petrishchev[1], and *L.* Tseiko[3]

[1]Federal Scientific Agro-Engineering Center VIM, 1 Institutsky proezd, 5, 109428, Moscow, Russia
[2]Russian State Agrarian University Moscow Timiryazev Agricultural Academy, Timiryazevskaya str., 49, 127550, Moscow, Russia
[3]Kaliningrad Research Institute of Agriculture, Branch of the V.R. Williams Federal Research Institute for Fodder Production and Agroecology, Slavyanskoye village, 9, Russia

Abstract. Reducing the excess costs of the consumer due to timely maintenance and increasing the efficiency of detecting deviations in technical condition to improve operational reliability is an important task in improving the efficiency of using energy-saturated tractors of domestic production. In order to promptly provide initial information on the degree of use and the current state of resource-determining parts and assemblies, as well as to increase the controllability and adaptability to diagnosis, indicator counters integrated into the design of tractors are used. Diagnostics and information collection allows us to prevent failures and minimize costs under the conditions of branded service, as well as to monitor the current state of equipment that is under warranty or under lease. In the production of energy-saturated tractors most of the main components and aggregates in the JSC "St. Petersburg Tractor Plant" transmissions are made independently, with the exception of bearings and friction discs. Therefore, in order to increase the operational reliability of the tractor as a whole the proposals for the development of indicator counters were carried out primarily to increase the controllability and adaptability to the diagnosis of power transmissions, as the most relevant for minimizing the costs of the manufacturer, leasing company, and end user. ***Keywords**:* sensor, diagnostics, technical service, transmission of energy-saturated tractors, tractor, repair. Producing plants, research teams and individual laboratories are engaged in research to solve problems of increasing the resource of agricultural machines and tractors. However, the main indicators of the reliability of agricultural machinery increase with low dynamics, and the cost of maintaining machines increases sharply in the post-warranty period of operation [1-3].

1 Introduction

The low dynamics of solving problems of tractor reliability lies in the lack of real consideration of the factors of the "man - machine - environment" system and the assessment

* Corresponding author: redizdat@mail.ru

of their interaction on the availability factor, resource due to the low adaptability to diagnostics and diagnozability of even those parts, with the wear of which the operation of tractors is not possible for technical or economic reasons [4].

From the point of view of reliability, the tractor transmission is a chain of a large number of assembly units, any failure of which during operation causes the necessary stop for repair or adjustment, i.e., entails the inability to perform the specified functions of the tractor as a whole [5].

In research [6-8] is proposed a prototype of a system for remote monitoring of the technical condition and operating rules of energy-saturated equipment, while there is a need to estimate the value of the usingcoefficient (load) and its distribution among individual resource-determining assembly units, which ultimately affect the availability coefficient.

The disadvantage of the proposed controls is the lack of clear criteria for the limit state approved by the producer (for new brands of equipment), and in the section of the operating rules of the instructions there are no reasonable numerical values that characterize the technical condition with the assessment of the degree of conscientious attitude of the operator to the entrusted equipment, as well as the specifics of the work [9-11].

1.1 The purpose of the work

Is to justify the use and development of prototypes of indicator counters to determine the need for maintenance operation and current assessment of the technical condition of individual resource-determining units based on their actual, functional use in the operation of equipment (for example, tractors of the K-701...K-744 R type).

The research methodology involved the following steps:

- development of mock-up samples of indicator counters that allow collecting and calculating the initial information for visualizing the process to the operator, as well as transmitting threshold state data to the telemetry terminal;
- experimental studies making to check the operability of devices and modeling the controlled parameters of the technical condition.

2 Practical implementation of research.

Currently, the existing mock-up samples of indicator counters have been prepared, which allow the production of:

- calculation of the number, time of use of gear changes and indication of the emergency level of the working fluid;
- indication of compliance with the gear ratios indication of the need to connect the rear axle by slipping the wheels of the front axle.

The presented meters-indicators taking into account the possibility of installation can be classified as external and built-in diagnostic tools, which can significantly reduce the time to prepare for diagnostics, and if necessary, reinstall to the new control object.

The experimental tests on base of the GB K-744 at KI-28340 stand, which was equipped with meters-indicators, initial data have been obtained for the possible evaluation of the general technical condition under operating conditions [12-14]:

- the volume of use of each transmission;
- reference characteristics of the time of pressure recovery in the gearbox when changing gears;
- amplitude and phase characteristics of the hydraulic pump;
- thickness of the package of friction discs;
- tightness of the channels of the distributor of the gearshift mechanism;
- slipping of friction discs by changing the gear ratio;

- radial clearance of shaft bearings;
- technical condition of hydraulic system filters.

Currently, the use of indicator counters, in the case of finding controlled values in the limit and emergency ranges of values, allows transmitting data on the situation in on-line mode to the logical or analog inputs of the telemetry terminal for logging events, which is especially important for power transmission units of energy-saturated equipment produced by JSC "St. Petersburg Tractor Plant", which is under lease, and also on warranty service in order to prevent its use in emergency modes. Thus, based on the organizational specifics, regional and climatic features of the work, initial information can be collected to calculate the remaining resource, and the operator's work and service time can be adjusted to ensure the performance of agrotechnical work.

The integration orientation of the research allows us to improve the proposed methods and choose mass-produced means for non-contact assessment of the technical condition, to obtain information for calculating the residual resource using direct measurements and the possibility of continuous monitoring of the actual change in the diagnostic parameters of the transmission units of K-701 tractors and their modifications. In order to obtain reliable initial data, it is necessary to implement the digital system of technical condition already at the assembly stage, testing the gearbox in stationary conditions comparable to the conditions of impacts during operation. The assumption (judgment) is formulated about the state of the objects of control and if necessary, the decision to stop work to prevent the failure of the power facility on the results are received on the control of the information (Figures 1 and 2).

Fig. 1. General view of the process of monitoring radial and axial displacement with using induction sensors.

a) distributing shaft; b) pressure discs of gear boosters;

1 - gearbox K-701, 2-induction sensor, 3-PC with the installed program for visualizing and logging the process.

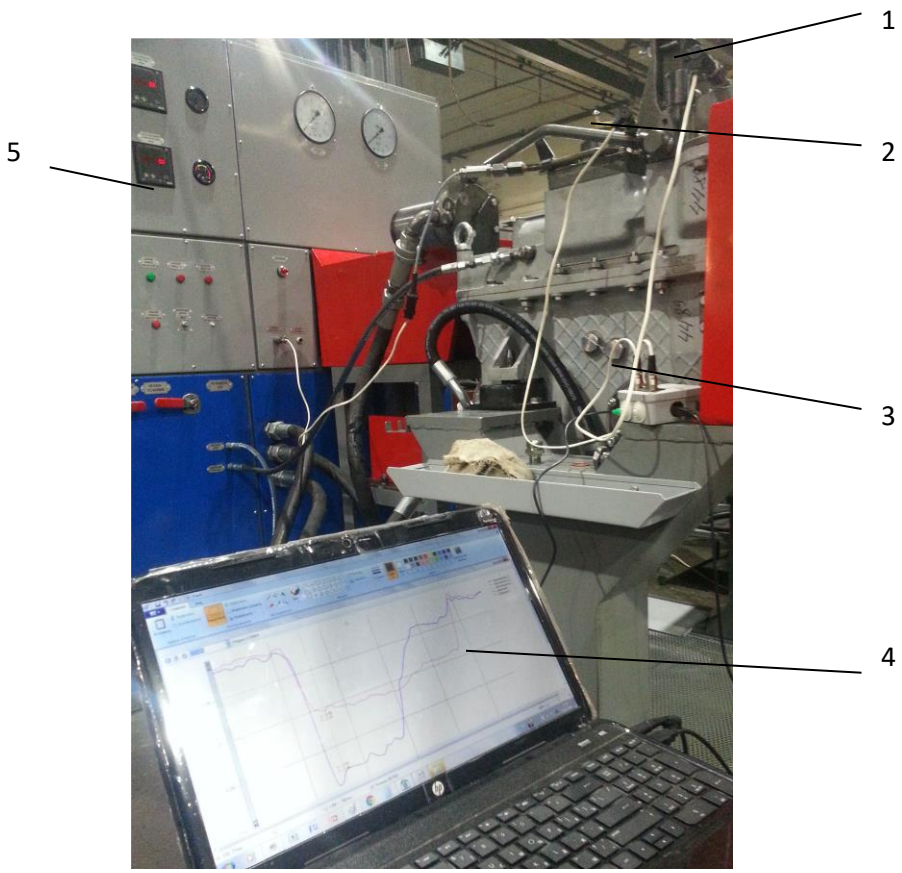

Fig. 2. Assessment and visualization of transients when monitoring the pressure recovery time in the gearshift mechanism at the stand.

1-sensor installed in the main hydraulic accumulator, 2-sensor at the pressure control point (place of installation of the standard sensor), 3 - the housing of the counter-indicator, 4- PC with the installed program for visualizing and logging the process, 5-stand for running-in of thegearbox KI-28340.

3 Results of research

As a result of the conducted research, a pilot production test of the developed experimental samples of indicator counters was carried out on control and diagnostic stands in the conditions of the Federal State Budgetary Scientific InstitutionFederal Research Center Agro Engineering All Russian Institute of Mechanization, K-701 tractors in the conditions of the Scientific and Production Association "Agroservice".

The test has shown high functional informativeness under the following conditions:

1. Assessment of the level of loading of hydraulic systems of the suspension to determine the technical condition based on the modes of their use in relation to the internal combustion engine, since the tractor can operate in transport mode (hydraulic system load factor up to 3 %), agricultural mode (hydraulic system load factor from 3% to 15%), industrial mode (hydraulic system load factor from 15% to 75%). Therefore, the maintenance of hydraulic systems must be carried out based on the actual level of use. This, it will make possible to

more rationally distribute the fleet of existing equipment of the same type by types of work in order to objectively assess the resource parameters of the suspension hydraulic system during the warranty and post-warranty time of use;

2. Carrying out comparative resource bench tests of repaired hydraulic pumps for an objective assessment of the quality of the work performed, spare parts, components according to the degree of compliance of the operating cycles at the nominal pressure of the repaired pump with respect to the new one;

3. The collection of primary data on the technical condition of kinematically connected components of the gearbox, the main transmission of the drive axles, the shaft motor, hydraulic pumps by the amplitude-phase method allows using non-contact distance measurement to estimate the minimum and maximum values of beats to calculate wear, distortions, deflections of rotating elements, to evaluate the unevenness (pulsation) of pressures in the pressure lines of pumps of the gearbox, hydraulic drive and convert the results into a dimensionless pulsation coefficient (ξ), which can characterize the nominal, permissible, maximum technical condition;

4. Checking of the technical condition of tractor (industrial) diesel engines by the gas flow rate breaking into the crankcase and exiting through the breather, with the possibility of transmitting a warning signal to the operator, the diagnostician or the on-line monitoring terminal in case of exceeding the limit or permissible preset values during operation, and during bench running-in, allows us to obtain initial data to assess the degree of running-in of the cylinder-piston group before and after repair;

5. Test evaluation of the general technical condition of the gearbox with hydraulic control of the K-701 tractor by the time of pressure recovery in the gearshift mechanism for compliance of the measured values with the nominal (up to 0.4 seconds), permissible (from 0.4 to 0.5 seconds) and limit (more than 0.5 seconds) assigned values, and in case of exceeding the permissible and the occurrence of limit values, it signals the operator about the event, and also simultaneously transmits data to the on-line monitoring terminal;

6. Determination of the energy parameters of the engine during the test acceleration of the crankshaft with the determination of the effective power and the assessment of the technical condition;

7. Determination and warning of the operator about the violation of the gear ratios laid down in the design, thereby checks the level of slipping of the friction clutches such as the hydro-mechanical and mechanical gearboxes of energy-saturated tractors, and is also an electronic assistant to the operator to indicate the need to connect the rear axle of tractors;

8. In order to check compliance with the rules of operation of energy-saturated tractors for driving accuracy (does the operator allow jerks, shock loads and sharp accelerations, indicating a sharp acceleration, braking, galloping);

9. In order to obtain initial data on the level of use of the guaranteed resource of friction discs by counting the number of inclusions and the time of use of each transmission in hydraulic-controlled gearboxes, which will increase the level of controllability and adaptability to diagnostics and operational reliability, reduce the risks of incorrect calculation of the equipment readiness coefficient for field work.

The use of a set of experimental samples of meter indicators allows us to switch from a planned preventive system of maintenance and repair of tractors based according to operating time to the maintenance system based on actual technical condition, by obtaining operational data for the implementation of a reliability-oriented maintenance program (RCM) and the implementation of a failure management policy aimed at effectively ensuring the required safety, readiness and economical operation according to the State Standard R 27.606-2013.

Considering that at the moment, producers of agricultural machinery to improve the efficiency of projects as a condition for the supply of components use the method of analysis

of types and consequences of failures (FMEA) according to the State Standard R 51901.12 [15].

During the experimental test the possibility of using additional options to the presented indicator counters as the tool for monitoring the technical condition of the gearbox (GB) has been revealed (Table and Figure 3).

Table. 1. Examples of using additional options of indicator counters to prevent the operation of the tractor K-701 gearbox and their modifications in emergency modes.

No.	Control parameter	Description
1	Discharge pressure after the pump suction filter	When the vacuum pressure value is more than the assigned value (for example, a value of more than -0.025 MPa) over the entire speed range of the drive shaft (controlled from a speed sensor mounted on the drive shaft flange), in order to avoid cavitation wear of the pump's pumping gears and unstable provision of the nominal compression force by the pressure disk of the booster pack of friction disks and their jamming caused by high viscosity of the working fluid, contamination of the pump's suction filter
2	Discharge pressure after the pump suction filter	If the oil level is less than 35 liters, it entails risks of unstable provision of the nominal pressure in the hydraulic transmission control system, and a pulse decrease in the nominal pressure of the booster pressure plate leads to slipping and overheating of the friction discs of the gears.
3	Discharge pressure after the pump suction filter	If the temperature exceeds the maximum assigned valuemore than 100 °C the alarm is triggered, which warns of excessive hydromechanical losses: slipping of the friction discs of the hydraulic compression couplings, low bearing efficiency; increased load, inefficiency of the gearbox oil thermal stabilization system (the cooling radiator is dirty).
4	Discharge pressure after the pump suction filter	The assigned criterion of serviceable technical condition is the absence of axial movement of any booster when the neutral gear is switched on on the GSM lever at the maximum speed of rotation of the drive shaft.
5	Discharge pressure after the pump suction filter	The assigned criterion of serviceable technical condition is the axial movement of the pressure disc up to 6 mm, permissible up to 8 mm, maximum over 8 mm
6	Discharge pressure after the pump suction filter	The assigned criterion of serviceable technical condition is a radial clearance of up to 0.25 mm

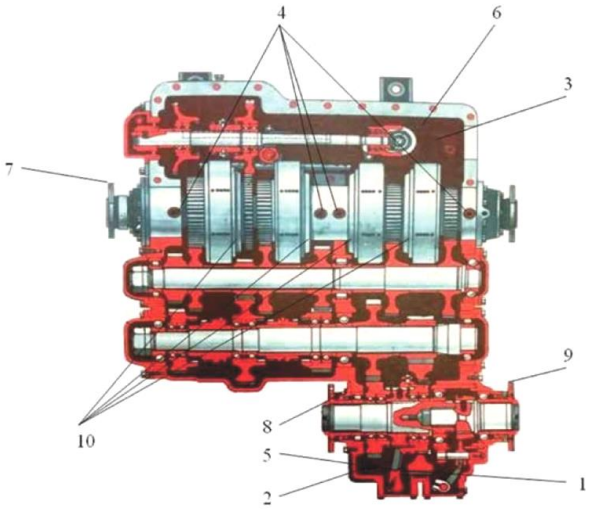

Fig. 3. Planned installation locations in the gearbox of additional sensors for monitoring.

1-emergency oil level, 2-oil temperature, 3-smoke (in the presence of emergency mechanical losses), 4 – oil pressure in the control system, 5 - discharge pressure (contamination of the suction filter), 6 - pressure in the cavity (contamination of the breather), 7 –speed of the drive shaft, 8 - the front drive axle, 9-the speed of the distributing shaft of the cargo (plug-in) axle, 10-axial and radial movement of the pressure discs of the gear boosters.

At the present stage of development of agricultural machinery we consider it appropriate to develop and adapt the proposed diagnostic system, which will allow monitoring compliance with the rules of operation of equipment. This will allow the owners (leasing companies) and the dealer's service department to provide information about the current state of resource-determining units and aggregates, the level of actual use. Also will reduce the uncertainty when performing service work, since the producers of individual components (friction discs, hydraulic drive, etc.) calculate the guaranteed resource in cycles and the general producer provides warranty support and routine maintenance work on the operating time of the diesel engine [16,17].

4 Conclusions

Thus, the experimental implementation of indicator counters at the level of expert assessments has shown the following possibilities:

- increasing the level of controllability and adaptability to diagnostics in order to minimize violations of the rules of operation of energy-completed tractors, including in extreme or emergency technical condition;

- prompt response to changes in the current general technical condition during daily maintenance, as well as resource diagnostics of diesel engines, gearboxes, hydraulic drives to increase the level of operational reliability of the operated equipment;

-increasing in the shift operating time by at least 30-50%, the reduction in downtime for technical reasons by 3-5 times, the increase in the technical readiness coefficient at the level of 95-97%, the number of repairs to eliminate failures of groups I and II is reduced by 15...25%, and excess maintenance costs are reduced by at least 3 times.

References

1. F.N. Tavlybaev, *Repair of tractors "Kirovets"* (GOSNITI, Moscow, 1993)
2. M.G. Degtyarev, *Methods and means of increasing the transmission life of tractors with a hinged frame* (Orel State Technical University, Orel, 2003)
3. C.V. Klyuev, P.P. Parkhomenko, V.E. Abramchuk et al., *Technical means of diagnostics* (Mechanical engineering, Moscow, 1989)
4. N.A. Petrishchev, M.N. Kostomakhin, A.S. Sayapin, I.B. Ivleva, Technical Service of machines **3(140)**, 12-20 (2020) DOI: 10.22314/2618-8287-2020-58-3-12-20.
5. E.A. Shuvalov, A.V. Boykov, B.A. Dobryakov, M.G. Panyukhin, *Theory and design of tractor "Kirovets"* (Mechanical engineering, Laningrad branch, Leningrad 1980)
6. A.P. Solomkin, O.V. Myalo, Omsk Scientific Bulletin **3(113)**, 75-78 (2012)
7. A.I. Zolotar, A.I. Goldbuch, G.A. Sokolova, *Development of methods of technical diagnostics of malfunction of pumps, hydraulic motors and other hydraulic equipment of mobile machines* (TSINTIKHIMNEFTEMASH, Moscow, 1991)
8. *Resource indicators of pumps,* URL: https://www.hydrosila.com/products/gear-pumps/performance-m /
9. *Resource indicators,* URL: https://gidroliga.com/hydrocylinders/reparation
10. *The nomenclature directory of the PRB "Molodechno Powder Metallurgy Plant"*, URL: http://zpm.molodechno.by/files/spravochnik.pdf
11. *Sintered friction composite materials and products,* URL: http: //www.science.by/upload/iblock/7f5/7f537983961941edddbff133162b39a7.pdf
12. V.I. Chernoivanov, V.V. Blednykh, A.E. Severny et al., *Maintenance and repair of machinery in agriculture* (GOSNITI, CHAGAU, Moscow-Chelyabinsk, 2003)
13. *Tire control system*, URL: https://alltpms.ru
14. A.S. Dorokhov, M.N. Kostomakhin, N.A. Petrishchev, I.M. Makarkin, A.S. Sayapin, I.B. Ivleva, Technical service of machines **4(137)**, 83-95 (2019)
15. V.E. Godlevsky, A.Ya. Dmitriev, G.L. Yunak, *Application of the method of analysis of types, causes and consequences of potential nonconformities (FMEA) at various stages of the life cycle of automotive products* (SE "Perspektiva", Samara, 2002)
16. N.M. Kostomakhin, V.I. Tseiko, M.N. Kostomakhin, N.A. Petrishchev, M. Hryniewicz, K. Mazur, Problems of intensification of animal husbandry, taking into account environmental protection and the production of alternative energy sources, including biogas, 71-82 (2021)
17. M.N. Kostomakhin, YU.V. Kataev, N.A. Petrishchev, A.S. Sayapin, K.K. Molibozhenko, Vestnik Mashinostroeniya **1**, 67-71 (2022) DOI: 10.36652/0042-4633-2022-1-67-71