Improving the reliability of hydraulic systems of technological machines

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Abstract. Modern technological machines have in their design hydraulic systems that are used to control the working body of the machine. Currently, hydraulic systems are complex systems that consist of a large number of subsystems and separately functioning elements. An analysis of the reasons leading to the failure of hydraulic systems shows that their reliability depends on a large number of factors, which are often interconnected. These factors include the external influence of the environment, the properties of materials and working hydraulic fluid, wear processes, the magnitude of the loads, the operating time, as well as regulations for the maintenance of the hydraulic system as a whole and its individual elements. As the statistics of hydraulic systems failure show, about sixty percent of failures are associated with contamination of the working fluid. It is possible to prevent contamination of the hydraulic system at the design stage or by changing the organization of maintenance. It is shown that the number of sensors registering the level of contamination of the hydraulic fluid and their placement on the machine body must be scientifically substantiated. The studies presented in the article allow us to make a conclusion about the possible formation of stagnant zones in remote nodes of the hydraulic system. An important result of this research is that dynamic data collected by the built-in particle detection sensors can give inaccurate information about the condition of the hydraulic fluid. Evaluation of modern methods of technical operation has made it possible to identify a priority condition that will allow the transition from diagnostic to predictive assessment of the state of elements of hydraulic systems of technological machines.

1. Introduction

Most technological machines, which include construction, road construction, earthmoving, have a hydraulic system as part of their design. With its help, the control of the working body and the movement of the machine itself are carried out. The hydraulic system of modern technological machines is a complex system, which includes a large number of elements. An analysis of the operation of hydraulic systems shows that the reliability of systems and components depends on a large number of factors, which are often interrelated. These include environmental parameters, properties of the materials used, wear, dynamic loads, duration of operation, as well as maintenance regulations. As statistics show, about 60% of hydraulic system failures are associated with contamination of the working fluid. Sources of pollution can be internal and external. Increasing the reliability of hydraulic systems can be achieved at the design stage by making changes to their design.
or during operation based on monitoring the operating parameters of the system, promptly changing the maintenance schedule.

Maintenance of hydraulic systems is an important part of the economic costs of enterprises operating technological machines. Equipment maintenance costs can account for up to 40% of the total operating costs [1-3]. The reason for such significant costs is the lack of systems for operational monitoring of the technical condition of hydraulic system elements. The existing maintenance regulations are aimed at ensuring the machine's operating life specified by the manufacturer under average loading conditions.

Research in the development of new and improvement of existing techniques for the maintenance of hydraulic systems is little covered in the scientific literature [4]. In this regard, the development of new approaches to improve the reliability of hydraulic systems, in particular through the introduction of dynamic data collection on the state of hydraulic fluid, is an urgent scientific task.

2. State of the issue

It is possible to increase the reliability of hydraulic systems through the use of high-quality (reliable) elements in its composition, a well-founded layout of the hydraulic circuit itself and the use of advanced maintenance methods.

In the Russian Federation, to standardize the maintenance of technological machines, the method of preventive maintenance is used, which, on the basis of statistical data on failures, makes it possible to develop regulations for the maintenance and replacement of elements included in the hydraulic system. This system works reliably during mass servicing of the same type of equipment operating with a load permissible in terms of magnitude and time. However, at present, in view of the large range of construction machines, the isolation and fragmentation of enterprises that operate them, machine manufacturers practically do not receive information about failures and the reasons for their occurrence. Leading foreign machine manufacturers, when selling, enter into long-term agreements with the buyer, which often include a service package, and this is perhaps the most common and effective way to ensure a high level of hydraulic system reliability [5]. The agreement provides for the collection of data on the state of systems and their operating conditions, which makes it possible to make adjustments to the design of machines at the design stage. The sale of maintenance or other services along with a complete machine is part of the Product-service system (PSS) methodology. This manufacturing approach has been developed to meet the needs and expectations of consumers and to reduce the economic costs of manufacturers. Organization of strictly regulated collection of statistical data on failures reduces production costs when creating new products and makes it possible to develop recommendations for extending the service life of machines in operation [6, 7].

The maintenance rationing methodology based on the collection and analysis of the cause-and-effect relationships of failure has a significant drawback, which is the low speed of obtaining information. To eliminate this drawback, large equipment manufacturers are introducing a large number of electronic sensors, which make it possible to create conditions for operational monitoring of the state of hydraulic systems. The use of electronic measuring devices allows for maintenance based on the analysis of the actual state of the elements of the hydraulic system (Condition Based Maintenance - CBM). This is the most progressive system for organizing the technical operation of SDM hydraulic systems at present. CBM is designed to prevent malfunction. Maintenance and repair of hydraulic systems are carried out depending on the current state of the system, which is monitored during operation without any disassembly and revisions, based on the control and analysis of the set parameters. This is achieved by monitoring and assessing the technical condition of the object by non-destructive testing methods or other types of periodic diagnostics. Maintenance actions are performed only when necessary. Diagnostic and predictive components are two important components in the overall CBM methodology, where diagnostics is responsible for detecting malfunctions, and predictive ones are responsible for preventing them and detecting deterioration [8]. The key processes of predictive maintenance are collecting sensor data, transforming the signal, and analyzing the received data. To improve the reliability of hydraulic systems, machine manufacturers must design monitoring
systems as part of the overall design of the machine. The location and number of sensors must be scientifically justified to maximize the useful knowledge they can provide when analyzing real-time data while minimizing the costs associated with installing and operating the sensors.

Caterpillar Inc. is the current leader in the use of hydraulic condition monitoring systems to predict problems. (CAT), Komatsu Ltd. and JCBamford Excavators Ltd.

Leading experts at CAT Ltd claim that the concentration of wear solids in the working fluid is a key indicator of potential hydraulic problems. [9-11]. Hydraulic component manufacturers such as BoschRexroth and Parker Hannifin set a range for their products based on internal clearances and operating conditions [12]. For example, pumps and valve manifolds that operate at high pressures with close clearance tend to require a higher level of cleanliness. BoschRexroth recommends that cleanliness levels be achieved based on the system requirements for operating the hydraulic system.

Electronic sensors (magnetic, optical or differential) are used to count the number of particles in the working fluid [13]. The most modern automatic particle counters use lasers. Particle counters built into the SDM hydraulic system (standardly installed) allow to collect data in real time during machine operation. At the same time, temporary penetration into the hydraulic system (connecting sensors, connecting, disconnecting pipelines) is not required, therefore contamination from outside is prevented.

For an unambiguous assessment of the ongoing changes in the purity of the working fluid, it is necessary to correctly determine the location of the stationary particle counters or the location of sampling for their subsequent analysis in the laboratory. British Standard (BS), BS5540 Evaluation of Particulate Contamination of Hydraulic Fluids, specifies procedures for obtaining samples of hydraulic fluid from hydraulic systems. Sampling is carried out through the sampling valves provided by the manufacturer or from the hydraulic tank. However, as studies show, the accuracy of counting the number of particles is influenced by the type of fluid movement (turbulent, laminar), the location of the particle recorder, and the particle registration method [14].

3. Research
Modern diagnostic methods based on counting pollutant particles in the working fluid analyze samples taken from the pressure line. To a lesser extent, attention is paid to dead-end nodes of hydraulic systems, in which stagnation of the working fluid is possible. This effect manifests itself when using long pipelines leading to the hydraulic cylinders. The piston of the hydraulic cylinder performs a cyclic reciprocating motion. If the volume of liquid in the pipeline going from the distributor to the hydraulic cylinder exceeds the volume of the piston or rod cavity, then a stagnant zone is formed. The fluid from the piston or rod end does not participate in the general circulation. Installation of a particle counter in the pressure line will not allow detecting the degradation of the remote unit (hydraulic cylinder).

In order to establish this effect, a number of samples of the working fluid were taken from different lines. The hydraulic system of the HBM motor grader TG 190TA-4 was used as the hydraulic system under study. Samples of the working fluid for analysis were taken from the main blade control hydraulic cylinder and the dozer blade hydraulic cylinder. In the course of the experiment, the following were determined: acid number of the working fluid (according to GOST 5985); mass fraction of mechanical impurities (according to GOST 6370); content of lead, iron, chromium (GOST 17216). These metals were chosen in view of their presence in the structure of hydraulic cylinders and their absence in the composition of the working fluid. The results are presented in tab. 1.

The analysis of the data obtained allows us to draw conclusions about the isolation of the working fluid in a remote unit from the fluid circulating in the main circuit of the hydraulic system. There is no chromium in the samples from the hydraulic cylinder of the bulldozer blade, and the share of lead and iron is less than in the main working body, which confirms the different degrees of circulation of the working fluid in the hydraulic system of the machine.
Table 1. Laboratory studies of samples of the working fluid of a motor grader.

| Sample name                      | Acid number, mg KOH | Mass fraction of mechanical impurities, % | Lead, mg / kg | Iron, mg / kg | Chromium, mg / kg |
|----------------------------------|---------------------|------------------------------------------|---------------|--------------|------------------|
| Main blade hydraulic cylinder    | 0.58                | 0.92                                     | 2.36          | 9.27         | 0.07             |
| Dozer blade hydraulic cylinder   | 0.27                | 0.68                                     | 0.42          | 8.8          | -                |

4. Conclusion

An important result of this research is that dynamic data collected by the built-in particle sensors can provide inaccurate information about the health of the entire hydraulic system. The installation of built-in contamination particle counters makes it possible to monitor hydraulic systems in real time; they have limitations in their accuracy depending on the type of fluid movement (turbulent, laminar), the location of the particle recorder, and the particle registration method.

Improvement of methods for diagnosing and designing hydraulic systems of machines will increase their reliability and durability, as well as reduce the number of unforeseen failures.

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