Improving the Reliability of Remote Nodes Hydroficated Machines

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Abstract. The article discusses the existing trends in the development of diagnostic methods for hydraulic systems of technological machines. A description of the methods for diagnosing hydraulic systems using various approaches is given. The studies of contamination of the working fluid in various sections of the hydraulic systems presented in the article confirm the inefficiency of the existing diagnostic methods used for modern technological machines. The presence of dead-end branches in hydraulic systems does not allow us to fully judge the technical reliability of the machine as a whole. The results of the analysis of samples of the working fluid of hydraulic systems of construction and mining drilling machines taken from different sections of hydraulic systems are presented.

1. Introduction
Modern technological machines are multifunctional, incorporate several working bodies. They have a complex control system and, as a result, the requirements for the reliability of individual nodes are increased. The composition of most technological machines includes a hydraulic system that performs the functions of controlling and transferring energy to the working bodies of the machine. As the statistics of failures on the hydraulic system show, about 50% of failures account for the total number of failures of the machine as a whole [3, 6, 10, 12, 13, 14]. In the hydraulic drive of road construction machinery, about 80% of failures are associated with contamination of the working fluid [1, 6]. Sources of pollution can be increased wear of the hydraulic system elements, the external environment, dishonest attitude to the maintenance and repair of equipment and others. In most cases, troubleshooting in the field is unacceptable, which entails the need to transport equipment to the repair site, which leads to large economic costs. In this regard, the development of new and improvement of old methods of technical diagnostics of hydraulic systems and its individual elements is an urgent research topic.

2. Analysis of hydraulic drive diagnostic methods
Diagnostic methods can be divided into two types, the first make a conclusion about the state of the system based on an analysis of a group of parameters of the steady-state movement of the working fluid (flow rate, pressure, volumetric efficiency, and others). [2] The first group contains the methods of statoparametric, kinematic, acoustic, amplitude-phase oscillations, and others, these methods are either highly accurate, highly laborious, and require the use of expensive equipment, or are simple, but
at the same time inaccurate. [1] The second group of methods is based on determining the state of the system based on the analysis of the state of the working fluid (mass fraction of impurities, acid number, alkaline number, inclusion of certain metals and nonmetals), the use of these methods allows us to assess the state of the working fluid and, accordingly, determine the frequency of its replacement, based on the intensity saturation with certain pollutants, it is possible to identify its source, and accordingly to determine the element subject to increased wear. Both methods make it possible to use electronic devices to fix the parameters of the hydraulic system, process the received data and create neural networks. Nowadays, the diagnosis of hydraulic systems based on the analysis of the properties of the working fluid is being actively introduced. [3,4,5,11] Today, there are systems that can monitor the status of the working fluid in real time, in conjunction with the analysis of the databases of the neural network. [4] This allows real-time monitoring of the state of the system and notifies the operator of the need for maintenance or replacement of one of the elements. [5] According to recent studies, to ensure the greatest degree of reliability of the hydraulic drive, it is necessary to diagnose it after every 10 hours of operation [6, 7, 15]. Sometimes it is simply not possible or impossible to implement some diagnostic methods with such a periodicity, which means that the role of classical diagnostic methods is not so great in comparison with methods based on real-time analysis.

3. Theoretical substantiation of the problems of modern hydraulic systems

The tendency to complicate the hydraulic drive of modern road construction machines has led to the emergence of a large number of nodes remote from the valve. An increase in the length of pipelines, cyclic (reciprocating) movements of the actuators with a low flow rate of the working fluid lead to the appearance of stagnant zones in the pipelines, in which the working fluid is not able to be cleaned of impurities in the filter elements.

To explain this phenomenon, we consider a simplified hydraulic circuit of a technological machine Figure 1.

![Figure 1. simplified hydraulic circuit](image)

1 - a pipeline, 2 - a piston cavity, 3 - a rod cavity, 4 - a hydraulic distributor, 5 - a hydraulic pump, 6 - a filter, 7 - a hydraulic tank.
If the volume of liquid in the pipeline (1) exceeds the volume of liquid in the working cavities of the hydraulic cylinder, the effect of stagnation of the working fluid in a remote unit, which will be the hydraulic cylinder, may occur. The effect of stagnation of the working fluid in this case is due to the laminar flow of the working fluid in the pipeline, as well as the fact that full mixing of the fluid is possible only after the valve (4). Pipeline (1) serves as both a pressure line and a drain line, this in turn leads to the need to deliver the working fluid to the valve (4), from which the liquid is already directed to the drain line, passes through the filter (6) and enters the hydraulic tank (7). Otherwise, the working fluid circulates exclusively within the pipeline. Replacing the working fluid in the system does not solve the problem of stagnation of the working fluid in the remote site. Changing the working fluid is an oil change exclusively in the hydraulic tank, in this case, the oil from the pipeline is drained to a small extent and only under the influence of gravitational forces, the bulk of the oil remains in the remote nodes. This effect will lead to an increase in the intensity of contamination of the working fluid in remote sites and, accordingly, to a decrease in reliability, as a result of the lack of filtration and mixing, which allows to reduce the concentration of pollutants.

The most susceptible elements to the effects of pollution are distributors, hydraulic pumps, hydraulic motors and valves [8]. In the remote nodes, the working fluid is gradually saturated with wear elements and, during the operation of the hydraulic system, a contaminated working fluid can damage the remote hydraulic drive elements.

Modern diagnostic methods based on the analysis of the working fluid analyze samples of the working fluid in the pressure line, which is the result of ideas about the complete circulation of the working fluid throughout the hydraulic circuit. Similar systems today have found application in technological machines with high cost. However, they do not provide information about the state of the working fluid in the remote nodes, which leads to a decrease in the effectiveness of this diagnostic method. To increase efficiency, it is necessary to take into account the processes occurring in the remote nodes and place the points of intake of the working fluid for diagnosis and in the pipeline of the remote nodes.

4. The study of the effect of stagnation of the working fluid

In order to identify the existence of the effect of stagnation of the working fluid in the remote nodes, a series of sampling of the working fluid samples from hydraulic systems of technological machines was carried out. Samples were taken from the hydraulic system of the HBM TG 190TA-4 motor grader used in road construction and road maintenance in the city of Perm. Samples were taken from the hydraulic cylinder of the main working body and the remote (bulldozer blade).

The results of laboratory tests of the working fluid are presented in table 1.

| Sample Name | Acid number, mg KOH per 1 g of oil according to GOST 5985 | Mass fraction of mechanical impurities,% according to GOST 6370 |
|-------------|----------------------------------------------------------|---------------------------------------------------------------|
| Blade hydraulic cylinder (piston cavity) | 0,58 | 0,92 |
| Hydraulic cylinder of the remote blade (stock cavity) | 0,27 | 0,68 |

In the working fluid, the maximum content of solids is 0.064%, according to GOST 17216-2001. In samples of working fluids from the hydraulic system of the grader there are serious excesses of the mass fraction of mechanical impurities, this is due to the high operating time and poorly organized maintenance system of equipment. It is worth paying attention to the difference in the degree of contamination of the working fluid in the two samples, the sample from the remote dump contains less pollutants, unlike the main one, but at the same time, the remote dump was used to a much lesser extent than the main one. The relevant data allow us to draw conclusions about the isolation of the
working fluid in a remote site from the fluid circulating in the main hydraulic circuit. Particular attention should be paid to sampling sites. In the case of the main working body, this is a piston cavity, which is characterized by a large volume of working fluid in comparison with the rod cavity. When considering remote nodes, it is necessary to consider each cavity of the hydraulic cylinder separately, since there may be cases when the effect will be characteristic exclusively of the stock cavity. The difference in the acid number of the working fluid in the samples also indicates the isolation of the working fluid in the remote site.

A spectral analysis of the working fluid samples was also carried out, which also indicated differences in the contamination of the working fluid samples. The amount of solids in the samples is presented in Table 2.

**Table 2.** Studies of the type and amount of metals in oil samples.

| Sample                  | Plumbum, mg / kg | Mechanical impurities | Iron, mg / kg | Chromium mg / kg |
|-------------------------|------------------|-----------------------|---------------|------------------|
| Blade hydraulic cylinder| 2,36             |                       | 9,27          | 0,07             |
| Blade hydraulic cylinder| 0,42             |                       | 8,8           | -                |

The difference in the spectral analysis of the working fluid samples also indicated differences in the contamination of the working fluid samples. In samples from a remote working body, chromium is absent, and the proportion of lead and iron is less than that in the main working body. It should be noted that the proportion of iron is not much different in the two samples, this may indicate the wear of the element containing iron in the design of the remote site. It can be assumed that the content may be due to a violation of the repair process and maintenance of equipment.

The second technological machine used for research was the BPM-2A underground drilling machine. Samples of the working fluid were taken from the hydraulic system in 5 places. Sampling locations on the drilling machine are shown in Figure 2.

**Figure 2.** Places for sampling the working fluid.
The smallest amount of mechanical impurities was found in the oil tank (3), in the remaining samples the proportion of impurities is higher, and with increasing distance to the sampling site, their contamination increases. The results of laboratory tests are presented in table 3.

Table 3. The results of laboratory tests of fluid samples.

| Tracked Parameter | Sample No. 1 (pressure filter of a small pump) | Sample No. 2 (pressure filter of a large pump) | Sample No. 3 (oil tank) | Sample No. 4 (pressure line of the drill) | Sample No. 5 (pressure line of the cable drum) |
|-------------------|-----------------------------------------------|-----------------------------------------------|------------------------|------------------------------------------|-----------------------------------------------|
| Mass fraction of solids% | 0,29                                          | 0,08                                          | 0,07                   | 0,12                                     | 0,10                                          |

The analysis of the working fluid samples showed that in one of the samples the mass fraction of mechanical impurities was significantly higher than in the others, this is sample No. 1, taken from the filter to which the sleeve fits, where repair welding was carried out.

Sample 2 is located at a small distance from the hydraulic tank, which ultimately affected the minimum difference in the content of solids. About five meters of the pipeline lead to the sampling site 5, which is reflected in an increase in pollution by 40% relative to the oil tank. About 11 meters of the pipeline lead to the sampling site 4, which also influenced the increase in contamination of the working fluid by 70%.

For the mining industry, the development of hydroficated machines with a telescopic machine, which allows for the strengthening of roof supports and core sampling, is particularly relevant, in this case, the appearance of nodes located at a considerable distance from the valve. An analysis of failures of mining equipment showed that about 50% of failures are caused by hydraulic drive elements, about 40% of them were the result of contamination of the working fluid. Statistical data was collected from enterprises' appeals to the manufacturer, some of the failures remained outside the scope of the study.

5. Conclusions
It is possible to solve the problem under consideration by improving the design at the design stage, by changing the position of the valves, it is precisely solving the problem at the design stage using operational data that will achieve the best result. For technological machines in operation, it is possible to increase the reliability of the hydraulic drive by introducing additional elements for cleaning the working fluid or elements providing full circulation of the working fluid. The introduction of filter elements into the pipeline of remote elements will reduce the contamination of the working fluid. A significant advantage of this solution is its low cost. It is possible to ensure full circulation of the working fluid in the remote nodes by introducing additional piping lines and check valves, so as to separate the supply and drain line of the working fluid. It is possible to increase the degree of reliability of diagnostic operations by developing algorithms for recognizing remote nodes and including them in a special list for individual diagnostics.

Improving the existing methods for diagnosing and designing hydraulic machines will increase the reliability and durability of equipment, as well as reduce the number of unexpected failures.

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