Analysis of change in the state of hydraulic drive of machines while in operation according to the diagnostic results

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**Abstract.** Technical diagnostics is a sphere of knowledge embracing theory, methods and means for defining the technical state of the objects. It is necessary for provision of security, functional reliability and efficiency of the technical object operation, as well as for reduction of the costs for its technical maintenance and reduction of the idle time losses caused by failures and premature shutdowns for maintenance. Therefore the objective of the paper is to analyze the change in the state of hydraulic drive of machines while in operation according to the diagnostic results. In order to achieve the set objective the authors used various experimental methods. The paper considers mutual influence of maintenance and technical diagnostics of hydrostatic drives of construction, track and some other mobile machines. It is shown that introduction of technical diagnostics allows transferring from the system of planned preventive repairs to the system of servicing the machines according to their actual technical state, which allows completely using the resource of a series of expensive aggregates. The authors described several main basic characteristics of change in the volume effectiveness of the hydraulic sets while in operation.

**KEYWORDS** Diagnostic parameter; Hours in operation; Hydraulic drive; Economic expenditures; Performance capability.

1. Introduction

The modern economic situation in Russia makes the scientists, economists and engineers face a series of relevant issues connected with effective functioning of the railroad transport. The main part of the fleet of the modern machines for construction and maintenance of the railways are the machines with volumetric hydraulic drive, the most widely used due to its well-known advantages.

The main peculiarity of operation of these machines is the fact that the entire volume of work is performed at the railroad lines in the “gap” in a limited time-frame. Availability of the machines significantly depends on the state of hydraulic drive, which is the reason of over 50 \% failures in the machines. Traditional methods ensuring reliability of hydraulic drives, based on the system of planned preventive repairs do not fully ensure the necessary result on one hand, and cause great material and financial expenditures, on the other hand.

The system of maintenance and planned preventive repairs started to form in the 1930s, when the first “Rules for Servicing Tractors and their Drawn Equipment and for their Field Maintenance” (1932), implied 8 stages of performing the works with obligatory change of a series of details. Thereafter they served a prototype for development of the maintenance system and planned preventive repairs of other machines. However, the idea, proposed as \footnote{\textit{Corresponding author, Tel.:} +84999782356.  
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early as in the 1940s by Professor G.V. Vedenyapin concerning performance of the works on demand, has not been fully implemented up to now.

The modern situation, formed over the last two decades, change in the methods and means for control causes the necessity in improving the theory and practice of hydraulic drives operation in construction and road machines, particularly, due to application of technical diagnostics, which allows controlling the state of hydraulic drive of the machines and more precisely setting the terms and volume of the servicing and maintenance works, helps supporting availability of the machines for performance of works, and forecasts the residual operating time and progress in hydraulic drive, its nodes and specific devices.

Development of the methods and means for technical diagnostics of hydraulic drives creates a new situation in operation and makes it possible to apply the individual approach to solving the tasks of maintenance policy. Technical diagnostics allows eliminating redundant assembly/disassembly works, defining real need in regulations, revealing and controlling the main performance indicators of hydraulic drive of the machines in operation, adjusting the terms of technical maintenance depending on intensity of the works. The diagnostics allows controlling the state of new or maintained machines during the warranty period, which contributes to higher quality of manufacturing and maintenance.

Technical Diagnostics of hydraulic drives of the machines is a relatively new section of science of mobile machines operation. Its bases were formed in early 1970s [1, 2], when volumetric hydraulic drive gained widespread use. The issues of technical diagnostics of complicated systems were studied by I.A. Birger [3], G.F. Verzakova [4], I.V. Petrova [5], B.G. Kim [6], I.P. Tersikhy [7] et. al. The issues of diagnostics of volumetric hydraulic drive were investigated in the papers by T.S. Alekseeva [8], S.I. Abramova [9], V.A. Korzhova [10], R.A. Makarova [11], N.A. Maltseva [12], T.S. Morozova [13], A. I. Pavlova [14], Yu.F. Ponomarenko [15], V.N. Sidorova [16], S.I. Shumeyko [17], S.B. Bagina [18], V.I. Barysheva [19], O.F. Nikitina [20] and others.

2. Materials and methods

Study of the theory and practice of maintenance and technical diagnostics allows concluding that the current methods of ensuring reliability and organization of the maintenance of hydroficated machines at the railroad transport do not allow obtaining the most effective solutions in the sphere of the process management of ensuring the readiness and performance capability from the perspective of economy, resource-saving and the technology and equipment themselves. Development of the mechanization processes of track and transport works requires working out scientific substantiation of the decisions made in the sphere of organization of technical functioning, particularly in the issues of forecasting the residual resource of hydraulic drive in general and particular devices.

The most efficient instrument for solving a circle of issues related to this problem is precise consideration of their interconnections between each other and with adjacent factors, as well as with the ways of influence on these factors. It requires the analysis of applicability of private theories and developments with the purpose of creating a single system of technical diagnostics of hydraulic drives, including both technical means and methodological developments concerning managerial decisions in the sphere of exploitation of hydraulic drives as complicated systems.

Usually the complexes of organizational and technical measures on maintenance and repair carried out as planned are united in a single planned preventive system. Apparently, the minimum economic expenditures will be achieved in case when the applied system of maintenance and planned preventive repairs (hereinafter MNT and PPR) ensures rather close compliance of the planned terms of the repair works performance and the time of emerging actual need in them on one hand, and compliance of the repair volumes to the actually required on the other hand [1, 2, 5, 7, 9, 11, 12, 14, 15, 18, 19, 20, 21, 22, 23]. Otherwise, the
additional expenditures connected with unplanned repairs and overestimated volumes of planned maintenances are inevitable.

3. Results and discussion

Current PPR system, as a rule, implies such frequency of MNT and PPR, which ensures full exploitation of the resource approximately at 10%, while the rest 90% are repaired ahead of time. The practice shows that consideration of such indicators as time between failures, fuel and service parts consumption etc., allows correcting the time of placing the machines for repair thus increasing their lifetime. Figure 1 shows the generalized regularity of expenditures for support of reliability and the maintenance frequency and operating time of the machines. Let us consider the frequency of the machines’ hydraulic drives maintenance according to PPR without application of the diagnostic means. The main parameter characterizing the change in the technical state of hydraulic drive in general and its particular elements is the volumetric performance [1, 2, 5, 7, 9, 11, 12, 14, 18, 19, 20, 21].

Figure 1

Figure 2 shows the change in the volumetric performance for a group of machines at maintenance and repair with the set frequency without applying the diagnostic means. Curve 1 characterizes change in the volumetric performance of various machines, while curve 2 – function of the time between failures distribution density for complex of the machines.

At the system of planned preventive repairs, maintenance of all the machines should be carried out each time in the same periods of operation \( t_1, t_2, t_3 \), when the probability of failure emergence of only one element is insignificant. At such frequency there is no sense in technical diagnostics, because the overwhelming majority of the machines during maintenance will have sufficient resource, i.e. the capacity of operating significant time periods without interference, ensuring exploitation of the machine to the next panned repair with high probability.

Figure 2

Maintenance and repair appointed considering the technical documentation (TD) imply diagnostic operations carried out in certain periods \( t \). Therewith the technical documentation should contain the value of the volumetric performance and other parameters of the hydraulic drive’s state, at which failure free exploitation up to the next examination is possible. Implementation of such maintenance is shown at Figure 3.

Apparently, in the point of the first examination \( t_{dl} \), values of the state parameters may not reach the critical value, i.e. these machines may operate without maintenance up to the next examination. Values of volumetric performance at Point \( t_{d2} \)

Figure 3

of two machines exceed \( \eta_g \), therefore they should be repaired, but one of them can operate without failures up to the next examination without maintenance, i.e. its parameter will reach the limit value \( \eta_n \) at point \( t_3 \).

Thus, preventive maintenance and repair of the machine with the application of technical diagnostics is characterized by the fact that due to more complete exploitation of the tolerance range for deviation of the state parameter and conduction of the diagnostics, the share of the complete implementation of the machine’s elements resources increases.
The main diagnostic parameter of hydraulic drive and its elements is volumetric losses of the operating liquid and performance – general and volumetric – at the standard pressure. If in the drive’s system the set pressure does not develop, it definitely belongs to the defective and repairable.

The model of change in the diagnostic parameter is based on the data of the statistics of change in the volumetric performance during the operation.

The experimental dependencies of change in the volumetric performance are of parabolic shape. Paper [5] suggests conducting the search of the function parameters \( \eta = f(t) \) based on the assumption that it is square and is represented as follows (Eq. 1):

\[
\eta = at^2 + bt + c
\]  

(1)

Values of the argument are selected as equidistant (Eq. 2):

\[
t_{k+1} - t_k = h = \text{const (} k = 1,2,3,\ldots,n\text{)}
\]  

(2)

which allows keeping the record from the mean value \( t_\text{mean} = (t_1 + t_n)/2 \) in the integral parts of the pace, having selected preliminarily odd number of the experimental data in five points of non-failure operating time.

Then we obtain as follows (Eq. 3):

\[
\eta = a_1 \left( \frac{t-t_{cp}}{n} \right) + b_1 \left( \frac{t-t_{cp}}{n} \right)^2 + c,
\]  

(3)

where parameters \( a_1, b_1, c \) are calculated by the following formulas at the odd number of the data (according to 5 points) (Eq. 4, 5):

\[
a_1 = \frac{1}{3H_2} \left[ 3 \sum_{k=1}^{N} \eta_k \cdot \left( k-M \right)^2 - \frac{N^2}{4} \sum_{k=1}^{N} \eta_k \right]
\]  

(4)

\[
b_1 = \frac{1}{H_1} \cdot \sum_{k=1}^{N} \eta_k \cdot \left( k-M \right); \quad c = \eta_{cp} - \frac{H_1}{N} \cdot a_1
\]  

(5)

where: \( H_1 = N(N^2 -1)/12; \) \( H_2 = N(N^2 -1) [N^2 - 4]/180 \)

Values \( H_1 \) are presented in the annexes of the mathematic statistics. For the case of five initial data \( H_1 = 10; \) \( 3H_2 = 42 \) the formulas of the following kind are used (Eq. 6):

\[
\eta = at^2 + b \quad (3)
\]  

(6)

Formula 6. is presented as preferable based on the following facts. By differentiating expression 1 with respect to \( t \) we will obtain the following (Eq. 7):

\[
\eta' = 2at + b.
\]  

(7)

However, at \( t = 0 \) (i.e. prior to exploitation) \( \eta' \) is also apparently equal to 0, because there is no phenomena of wear. But in this case also \( b=0 \), and thus we obtain expression 3. Expression 1 should be apparently deemed as just formal description of the change in the nature of the volumetric performance during the operation, which may be good in some cases.
Physical meaning of expression 3 is narrowed to the following: the tempo of the volumetric performance drop is an ascending value, which is explained by accumulation of the wear debris and abrasive materials in the operating liquid on one hand and increase in the friction and projectile forces in micrometric pairs, on the other hand.

For small time sections the nature of the change in volumetric performance is satisfactorily described by linear dependence [9]. Let \( \eta \) be defined in point \( t_1 \) and \( \eta_2 \) in point \( t_2 \). Ratio (Eq. 8):

\[
\eta' = \frac{\eta_1 - \eta_2}{t_2 - t_1}
\]  

(8)

Let name \( \eta \) average velocity of change at time interval \( (t_1, t_2) \). If to assume that this velocity is further preserved during some section of time \( \tau << (t_2 - t_1) \), MNT, the values of volumetric performance may be predicted, which is after \( \tau \) operating hours is equal to the following (Eq. 9):

\[
\eta(t_i + \tau) = \eta_i - \eta' \tau
\]  

(9)

As practice shows, for small time intervals \( \tau \) the considered allowance is correct (approximately for interval 240 - 300 hours of operating time according to the hour-meter of the machine).

For a group of machines the area of lowered volumetric performance will be apparently limited by the following curves (Eq. 10):

\[
\eta_1 = -A_1 t^2 + B; \quad \eta_2 = -A_2 t^2 + B
\]  

(10)

where \( B \) – initial value of the volumetric performance

Definition of particular values of the dependency parameters (10) requires the following data: minimum and maximum operating time to the limit state, initial and limit value of volumetric performance. At the same time, initial value of the diagnostic parameter - \( B \) is apparently possible to accept their certified values for specific devices of hydraulic drive, because for new devices their spread is insignificant and they may be neglected, while for a particular group of devices parameter \( B \) will be equal as follows (Eq. 11):

\[
B = \prod_{i=1}^{n} B_i
\]  

(11)

The data obtained during the research conducted at the chair “Track and Construction Machines and Robot Systems” of the Russian University of Transport (Moscow State University of Railway Engineering) allowed obtaining the following data, summarized in Table 1.

### Table 1

Relevant Dependencies are presented at Figures 4 - 9.

Figures 4, 5, 6, 7, 8, 9
4. Conclusion

Therefore, increase in the exploitation of complicated and expensive technical systems, including hydraulic drives, applied in various industries as executive organs of the control systems and automation of the production processes, drives of operating machines’ organs, as well as requirement of security, no-failure operation and durability make assessment of their technical state rather important. Efficiency of exploitation of such machines to a greater extent depends on availability of the modern methods and means for diagnostics of hydraulic drives. Analysis of the obtained dependencies explicitly shows that the drives mainly powered by gear type and vane type pumps, have the maximum time spread of limit values achievement according to the parameter of volumetric performance. In order to achieve maximum efficiency of hydraulic drives in operation this circumstance should be considered at designing new machines, on one hand, and planning the orders for the spare parts, on the other hand. The authors have stated that the main diagnostic parameters of hydraulic drive and its elements are the volumetric losses of the performance operating liquid.

Also the dependencies of changes in volumetric performance of roll drive, linear motion drive, hydraulic actuators, axial piston hydraulic machines, spool valves, gear and vane pumps were constructed. The author has stated that the complexes of organization and technical measures on maintenance and repair carried out as planned are united into the single planned preventive system.

References


Table 1. Parameters of Change in Volumetric Performance of Hydraulic Drives

<table>
<thead>
<tr>
<th>Hydraulic Valves</th>
<th>Single-Bucket Excavators</th>
<th>Transport Construction Machines</th>
<th>Track Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$A_{max}^+ A_{min}^- A_{mean}$ $\cdot 10^{-6}$</td>
<td>$A_{max}^+ A_{min}^- A_{mean}$ $\cdot 10^{-6}$</td>
<td>$A_{max}^+ A_{min}^- A_{mean}$ $\cdot 10^{-6}$</td>
</tr>
<tr>
<td>Roll Drive (in general)</td>
<td>$0.012 \div 0.065$</td>
<td>0.895</td>
<td>0.070 \div 1.40</td>
</tr>
<tr>
<td></td>
<td>$0.0385$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear Motion Drive (in general)</td>
<td>$0.008 \div 0.050$</td>
<td>0.94</td>
<td>0.050 \div 1.30</td>
</tr>
<tr>
<td></td>
<td>$0.029$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axial Hydraulic Piston Machines</td>
<td>$0.00395 \div 0.0283$</td>
<td>0.95</td>
<td>0.029 \div 0.103</td>
</tr>
<tr>
<td></td>
<td>$0.01612$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gear and Vane Pumps (for track</td>
<td>$0.055 \div 0.22$</td>
<td>0.92</td>
<td>0.037 \div 1.16</td>
</tr>
<tr>
<td>machines)</td>
<td>$0.091$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic Cylinders</td>
<td>$0.00088 \div 0.0505$</td>
<td>~1.0</td>
<td>$0.003 \div 0.01$</td>
</tr>
<tr>
<td></td>
<td>$0.02569$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spool Valves</td>
<td>$0.00343 \div 0.01236$</td>
<td>0.99</td>
<td>$0.0101 \div 0.022$</td>
</tr>
<tr>
<td></td>
<td>$0.007895$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Dependency of the Expenditures on Support of the Machines’ Reliability: 1- Aggregate Expenditures on Maintenance and Repair among the Fleet; 2- Distribution of the Lifetimes of the Hydraulic Drive Main Aggregates; 3 – Unplanned Repairs (depending on the PPR frequency); a – Optimal Time of Maintenance and Repair
Figure 2. Change in Volumetric Performance of Hydraulic Drive for a Group of Track Machines with the Set Frequency of Maintenance without Applying Diagnostic Means: $h_{\text{initial}}$ – nominal (initial) value of the volumetric performance; $h_{\text{limit}}$ – limit value of volumetric performance; $t_i$ – frequency of MNT or repair; $t_{oi}$ – residual (underutilized) resource of hydraulic aggregates; $dF$ – distribution density of the hydraulic drive operating time for a group of machines to the limit state.

Figure 3. Change in Volumetric Performance of Hydraulic Drive for a Group of Track Machines at Control Preventive Maintenance with Application of the Diagnostic Means: $H_{\text{initial}}$ – nominal (initial) value of the volumetric performance; $H_{\text{limit}}$ – limit value of volumetric performance; $H_d$ – accepted value of volumetric performance; $t_i$ – frequency of preventive examinations; $t_{oi}$ – residual (underutilized) resource of hydraulic aggregates; $dF$ – distribution density of the hydraulic drive operating time for a group of machines to the limit state.
**Figure 4.** Change in Volumetric Performance of Roll Drive

**Figure 5.** Change in Volumetric Performance of Linear Motion Drive
Figure 6. Change in Volumetric Performance of Hydraulic Cylinders

Figure 7. Change in Volumetric Performance of Axial Piston Hydraulic Machines
Figure 8. Change in Volumetric Performance of Spool Valves

Figure 9. Change in Volumetric Performance of Gear and Vane Pumps
Biographies

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