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New method for monitoring the residual life of high pressure hoses

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New method for monitoring the residual life of high pressure hoses

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Abstract. The presented method is designed to monitoring the residual life of hydraulic drive elements. In this work, as an element of the hydraulic drive, high-pressure hoses are used, which are used in hydraulic drives of technological equipment of transport and technological machines. As a diagnostic parameter that characterizes the technical condition of the high-pressure hose, the frequency of natural oscillations of the pipeline with the liquid is adopted. Experimentally, the dependence of the natural oscillation frequency of the high-pressure hose on the dynamic loading cycles of the harmonic type was obtained, which were used to determine the probability of failure of pipelines and to find a strategy for their replacement. The probability of failure of high-pressure hoses for different periods of operation is determined on the basis of the obtained experimental dependences of the natural vibration frequency of pipelines on their operating time. Using the obtained dependences of the probability of failure of high-pressure hoses, it is possible to determine the possible residual life of pipelines and the need for their replacement. This method can be used to determine the probability of failure of other elements of the hydraulic drive, such as hydraulic cylinders, hydraulic valves, pumps, and others.

1. Introduction

Ensuring reliable operation of hydraulic drives during the full life cycle is one of the ways to improve the environmental safety of hydrofected machines. A significant amount of work has been devoted to this task [1-9], which is based on the development of technical solutions that allow for the occurrence of emergency destruction of high-pressure hoses to minimize hydraulic fluid emissions into the environment. The number of works devoted to forecasting the state of high-pressure hoses is insignificant [10, 11].

Currently, for the entire period of operation, the cost of repair and maintenance of transport and technological machines due to sudden loss of performance is several times higher than the cost of a new machine [12, 13]. The experience of operating foreign-made forest machines in Russia has shown that even for machines with higher reliability, the problem of sudden failures of high-pressure hoses has not yet been solved.

2. Materials and methods

Purpose: development of a method for monitoring the residual life of high-pressure hoses. Research method: mathematical modeling based on the provisions of hydromechanics and hydrodynamics.

To determine the probability of failure of high-pressure hoses as a control parameter that characterizes their technical condition, the frequency of natural oscillations of the pipeline with the liquid was adopted. This control parameter is selected based on the results of experimental studies conducted on the stand that simulates the operation of the manipulator and shown in figure 1.

Figure 1. The appearance of the stand for the study of high-pressure hoses.

High-pressure hoses of various lengths were tested. On figure 2 shows the dependence of the logarithmic decrement of oscillations of the pipeline length l = 1,17 *m* on the pressure, which is observed to have a pronounced minimum logarithmic decrement of oscillations (δ), which indicates the possibility of occurrence of resonant oscillations in pipelines at certain values of liquid pressure.

In this regard, the nature of the change in this parameter during the operating time of the machine is of interest. Experimental studies have also proved that the minimum value δ can be determined by the value of the natural vibration frequency of the pipeline with the liquid (f_c).

To determine the nature of the change in the natural frequency of oscillations of the high-pressure hose length l =1,17 *m* from the operating time, experimental studies were conducted on the stand for dynamic loading of the harmonic type, the results of which are presented in figure 3.

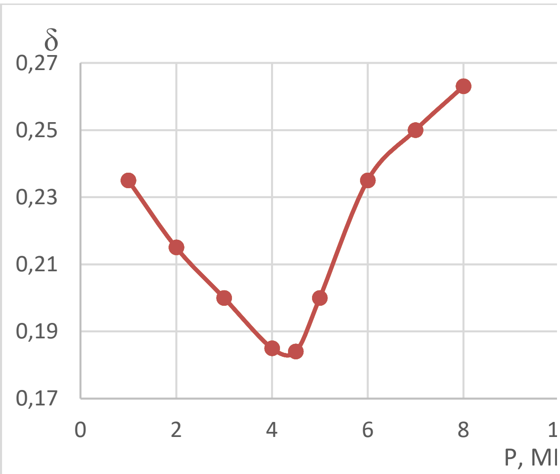

Figure 2. Dependence of the logarithmic decrement of oscillations (δ) from the liquid pressure to the high-pressure hose length l=1,17 *m*.

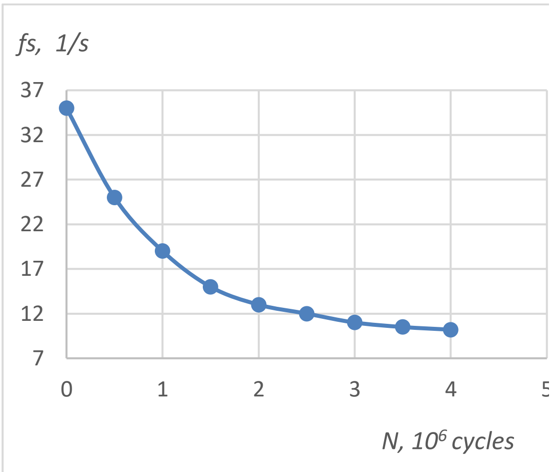

Figure 3. The dependence of the frequency of natural oscillations of the high-pressure hose length l=1,17 on the loading cycles.

As a result of processing statistical data on high-pressure hoseresources obtained during the operation of eleven John Deere 1910 machines with a volume operating time of 2250 operating hours for 2013-2016 on the basis of LLC «luzales» in the Republic of Komi (78 high-pressure hose failures were recorded), dependences of the empirical and theoretical functions of the distribution of high-pressure hose failures were constructed and it was proved that the high-pressure hose resource has a normal distribution law.

In the Republic of Komi, as in other Northern and North-Western regions of the European part of Russia, the winter period lasts about 7 months. In this regard, it is necessary to determine the probability of failure of the high-pressure hose in different periods of operation of forest harvest machine. Winter is considered the period of operation when the outdoor temperature is set below plus 5 ^oC.

We will determine the probability of failure of the pipeline in the summer and winter periods of operation. To do this, enter the following event values: A - failure of the rubber pipeline; B_1 - temperature in the summer period of operation; B_2 - temperature in the winter period of operation. Using the dependence of the total probability of events, we determine the probability of failure of the pipeline:

$$P(A) = P(B_1) \cdot P(A/B_1) + P(B_2) \cdot P(A/B_2), \tag{1}$$

where $P(A/B_1)$и $P(A/B_2)$ – conditional probabilities of pipeline failure in different periods of operation.

Since the events B_1 and B_2 form a complete group of incompatible events, then the sum of their probabilities is equal to one:

$$\sum_{i=1}^{n} P_i = 1\,,\; P(B_1) + P(B_2) = 1. \tag{2}$$

Knowing the periods of summer and winter operation for the northern regions, you can find the probabilities of events B_1 and B_2: $P(B) = \frac{n_N}{n_k}$, $P(B_1) = \frac{5}{12} = 0{,}417$, $P(B_2) = \frac{7}{12} = 0{,}583$,

where n_N - number of months of the corresponding work period; n_k - the total number of months in the year.

The analysis of statistical data showed that in the winter period of operation the resource of high-pressure hoses is approximately 2.5 times less than the resource during operation in the summer (the data were obtained when testing high-pressure hoses in the Republic of Komi), we get the equation of the probability of failure of pipelines with their different operating time t_i :

$$P(A)_{ti} = P(B_1) \cdot P\left(A/B_1 \right)_{ti} + P(B_2) \cdot P\left(A/B_2 \right)_{0,4ti}. \tag{3}$$

We introduce the following assumptions, which is legitimate in view of the different service life of the high-pressure hose in the summer and winter periods of operation:

$$\begin{aligned} f_{1/t_i} \cdot P\left(A/B_1 \right)_{t_i} &= f_{2/0,4t_i} \cdot P\left(A/B_2 \right)_{0,4t_i}; \\ f_{2/t_i} \cdot P\left(A/B_2 \right)_{t_i} &= f_{1/2,5t_i} \cdot P\left(A/B_1 \right)_{0,4t_i}, \end{aligned} \tag{4}$$

where f_{1/t_i} - natural frequency of oscillations of the pipeline with the liquid at the appropriate operating time in summer operation; f_{2/t_i} - natural frequency of oscillations of the pipeline with the liquid at the appropriate operating time in winter operation.

Solving equations (4) together, we determine the probability of pipeline failure during their summer and winter operation:

$$P\left(A/B_1\right)_{t_i}=\frac{P(A)_{t_i}}{P(B_1)+P(B_2)\cdot\dfrac{f_{1/ti}}{f_{2/0,4ti}}};\quad P\left(A/B_2\right)_{t_i}=\frac{P(A)_{2,5t_i}}{P(B_2)+P(B_1)\cdot\dfrac{f_{2/ti}}{f_{1/2,5ti}}} \qquad (5)$$

Substituting in the equations (5) certain values of the probabilities of events and, we obtain the calculation equations

$$P\left(A/B_1\right)_{t_i}=\frac{P(A)_{t_i}}{0{,}417+0{,}583\cdot\dfrac{f_{1/ti}}{f_{2/0,4ti}}};\quad P\left(A/B_2\right)_{t_i}=\frac{P(A)_{t_i}}{0{,}583+0{,}417\cdot\dfrac{f_{1/ti}}{f_{2/0,4ti}}}. \qquad (6)$$

As a result of experimental studies [12, 14, 15] it was found that during the entire service life of the forest harvest machine makes about 573,000 working cycles, which corresponds to 4000 hours of operating time. For each working cycle in the hydraulic drive, on average, there are about 12,3 fluid pressure emissions (changes in the fluid pressure in the pressure cavity of the hydraulic drive boom when processing wood). This provides a basis for finding the ratio between the number of loading cycles of pipelines during their laboratory testing and the operating time of machines in hours.

3. Results and discussion

Substituting in the equation (12) the values of probabilities $P(A)_{ti}$ and the values of the natural frequencies of oscillations of pipelines obtained experimentally (accepted pipeline length l =1,17 *m*) under different operating conditions, we get the probability of failure of the high-pressure hose in the event of B_1 and.

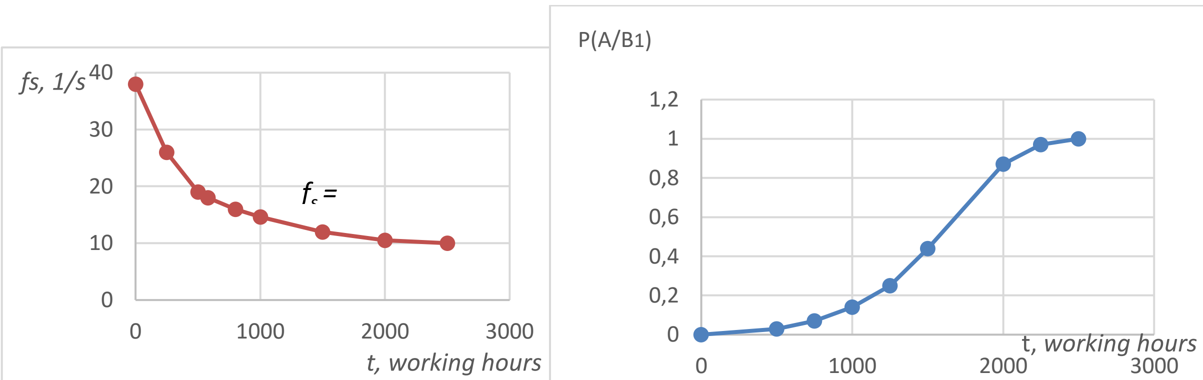

Figure 4. Probability of failure high pressure hose length l = 1,17 *m*.

Based on the results of the calculations, the dependences of the change in the probability of failure of high-pressure hoses during their operation in summer and winter are constructed (figure 4).

These dependencies can be used to predict the residual life of the high-pressure hose. For example, after monitoring a pipeline with an unknown operating time, the value of its natural oscillation frequency is equal to $f_c = 16c^{-1}$. To determine its residual resource in the winter period, draw a horizontal line through the value to $f_c = 16c^{-1}$ the intersection with the curve $f_2 = f(t)$. Through the intersection point, draw a vertical line to the curve and get the value probability of failure of the pipeline – 0,43, which corresponds to its operating time in the winter period of 550 *hours*.

Therefore, the remaining resource will be equal to $t_{rem.res.}$ = 450 *hours*. If the operation of the pipeline is expected in the summer, then its residual life is equal to $t_{rem.res.}$ =1125 *hours*, it is necessary to use a curve $P(A/B_1)$.

4. Conclusion

1. The developed method for control of residual life of high pressure hose using the obtained dependences of the frequencies of the high pressure hose from the load cycles and the empirical dependences of the distribution function of failures characterized in that allows to predict the remaining life of the hoses of high pressure during operation of the hydraulic machines in the summer and winter
2. When operating high-pressure hoses at negative temperatures, there is a significant decrease in their resource, which is confirmed by the results of experimental studies.

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