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Oscillating method for monitoring the technical condition of the hydraulic cylinders of manipulator machines

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Abstract. The substantiation of the oscillatory method for monitoring the technical condition of the hydraulic cylinders of manipulator-type machines is presented on the example of the boom hydraulic cylinder of a John Deere 1470 forest machine. The results of numerical simulation of dynamic processes in pressure cavities of hydraulic cylinders of manipulator-type machines are described on the basis of a developed mathematical model based on the method of theoretical description of the hydraulic drive structural components using hydromechanical circuits. The hydraulic system of the hydraulic drive boom was adopted as the calculated one. For the formation of dynamic processes in the pressure cavity of the hydraulic cylinder of the boom drive of the described machine, a shut-off valve installed in the drain line is used. This valve made it possible to provide an almost instantaneous stop of the piston, resulting in a hydraulic shock. The calculations also used the method of forming a hydraulic shock with an almost instantaneous stop of the piston at the end of its stroke. The research allowed us to justify the most informative parameter for monitoring the current technical condition of hydraulic cylinders in the functional mode-the logarithmic decrement of damped oscillations, as well as to develop a new hydro-shock method for monitoring the technical condition of hydraulic cylinders.

1. Introduction

The reliability of the operation of hydroficated machines components is, on the one hand, an important factor in ensuring its competitiveness, and on the other hand, is the most important factor in preventing environmental pollution during accidental discharge of working fluid. A significant amount of work has been devoted to solving the problems of minimizing the consequences of hydraulic drive failures [1-9].

Work on predicting the technical condition and failure of hydraulic drive is underway, but to a much lesser extent [10-11]. Therefore, the importance of the task of developing new methods for monitoring the reliability and technical condition of the hydraulic elements of manipulator machines is constantly increasing.

This article is devoted to the development of an oscillatory method for monitoring the technical condition of hydraulic cylinders of manipulator machines based on the analysis of the laws of dynamic processes in the hydraulic cylinder with its different technical condition.

2. Materials and methods

The purpose of this work is to substantiate the oscillatory method for monitoring the technical condition of hydraulic cylinders of manipulator machines (for example, the hydraulic drive of a forest harvesting machines type Harvester John Deere 1470, then JD 1470), based on the use of hydro-shock processes in the test and functional modes of their operation.

To achieve this goal, the tasks are set: to develop a mathematical model and conduct numerical simulation of dynamic processes occurring in the hydraulic cylinders of the manipulator machine as a result of hydro-shock impact, as well as to justify the oscillatory method for monitoring the technical condition of hydraulic cylinders.

The object of the study in this work was selected the hydraulic cylinder of the boom of a Harvester JD1470 forest machine, which has rubber seals that are subject to increased wear when working in the northern regions [13, 14, 15].

The hydraulic system of a hydraulic drive of an boom of a forest machine Harvester JD1470F is accepted as a calculation for substantiation of a method (figure 1).

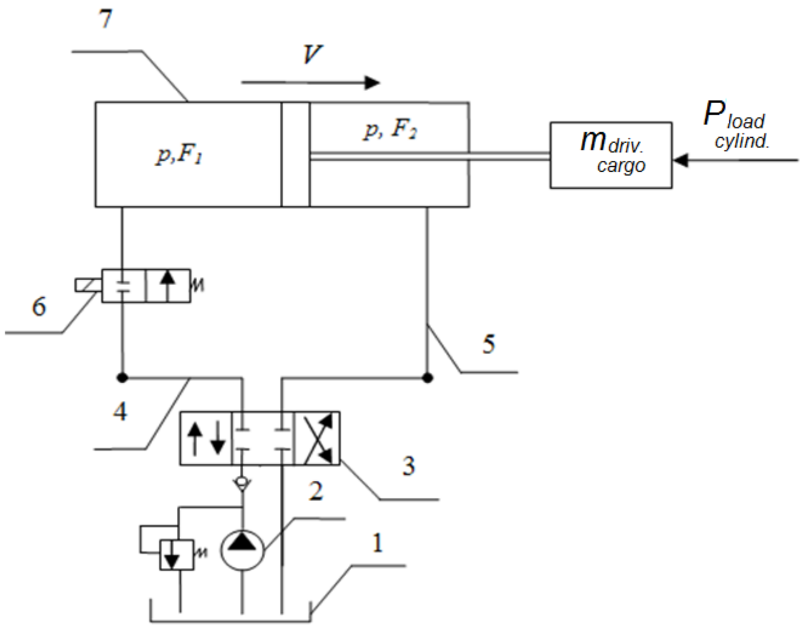

Figure 1. The hydraulic diagram of the hydraulic boom of the forest harvesting machines Harvester JD1470 with a shut-off valve.

From the hydromechanical circuit of the hydraulic drive of boom forest harvesting machines JD1470 for further research isolated cylinder, because when triggered, the shut-off valve causing the hydraulic shock, the remaining circuit elements are turned off. The described hydromechanical chain of the hydraulic cylinder of the boom of the forest machine JD1470 with a shut-off valve is shown in figure 2.

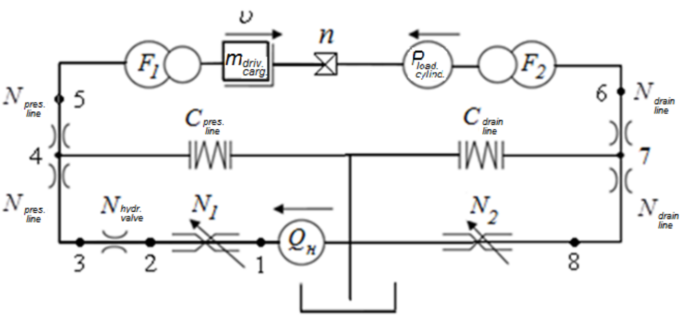

Figure 2. Hydromechanical circuit pressure cavity of the hydraulic cylinder of the boom of the forest harvesting machine JD1470F with shut-off valve.

Using the presented circuit, we will calculate the conditions for the occurrence of a transient process when creating a hydroshock impact with a sharp shut-off of the shut-off valve spool, as well as the influence of the state parameters of the hydraulic cylinder elements (piston and rod seals) that change during operation on the diagnostic parameter. When calculating the position of the system is taken: the load is in the lowest position, the Windows of the spool distributor are open, the liquid is fed into the piston cavity of the hydraulic cylinder, the shut-off valve is open.

When analyzing hydro-mechanical circuits, we will use the rules of contours and pipe joint.

Equations pipe joint:

$$\sum_{i=1}^{n} Q_i = 0, \ \sum_{i=1}^{n} \upsilon_i = 0, \tag{1}$$

where (Q_i) - The flow rate, (υ_i) the speed in pipe joint whose sum is equal to zero.

In this case, the unknown values are the pressure differences between the selected reference pipe joint and other pipe joint s in the chain.

The total number of independent pipe joint pairs is

$$j_s = j - 1 = 6 - 1 = 5, \tag{2}$$

where j - the number of pipe joint in the chain.

In the described hydro-mechanical chain there is one "long" branch, which is considered as one element, and 5 pipe joint.

The "long" branch " is described by the following equation

$$p_5 \cdot F_1 - m_{driv.carg.} \frac{d\upsilon}{dt} - f \cdot P_{load.cylind.} - F_2 \cdot p_6 = 0, \tag{3}$$

where F_1 и F_2 - the surface area of the cylinder rod exposed to the pressure of the working fluid at points 5 and 6 of the hydraulic circuit; p_5 и p_6 - pressure at points 5 and 6 of the hydraulic circuit; $m_{driv.carg.}$ - driven cargo; $d\upsilon/dt$ - the acceleration of the driven cargo; $P_{load.cylind.}$ - load on the hydraulic cylinder; f - the coefficient of friction of the rod on the piston seal.

A number of factors have been taken into account in the design of the chain and the following assumptions and limitations have been accepted:

1. The hydraulic cylinder is loaded with a constant force $P_{load.cylind.} = m_{driv.carg.} \cdot q$, *KN*, directed towards the rod cavity.

2. The rod of the hydraulic cylinder is connected to the concentrated cargo $m_{driv.carg.}$.

3. The initial position of the system-the cargo is lifted, the spool distributor are closed

4. The cavities of the hydraulic cylinder are characterized by active areas F_1, F_2 and pliability C_1, C_2.

5. The friction resistance of the piston against the cylinder liner is assumed to be proportional to the first degree of speed and is taken into account by the linear friction resistance γ. This assumption is caused by the fact that in the diagnosis mode, the piston path (friction path) is very small, so the nonlinear properties of the hydraulic cylinder can be neglected.

6. Oil flows from the pressure cavity to the drain are evaluated by hydraulic resistances $N_{pres.}$. N_{drain} and volumetric deformations (pliability) $C_{pres.}$, C_{drain}, moreover, the resistance of the pressure and drain lines are assumed to be equal, and the pliability-different.

To determine the diagnostic parameters for hydraulic shock inside the hydraulic cylinder, we will accept the following assumptions:

1. On the section from the pipe joint the expense for deformation of this section is determined by the equation:

$$Q_1 = C_{лин} \frac{dp_3}{dt}, \tag{4}$$

where $C_{шл}$ – pliability of the hydraulic cylinder rubber seals when pressure occurs.

2. The response time of the shutoff valve during hydraulic shock does not affect the flow time of the hydraulic shock.

In this case, the excess pressure during hydraulic shock can be determined by the Zhukovsky formula:

$$\Delta p = \rho \cdot \upsilon_0 \cdot \grave{a}, \tag{5}$$

where ρ - the density of working fluid, *kg/m*^{3}; υ_0 - the speed of propagation of hydraulic shock, *m/s*; $\grave{a}$ - the change in speed that results in a hydraulic shock, *m/s*.

Fluctuations of fluid during hydraulic shock will be described using the Fourier series (arbitrary function f with a period T):

$$f(x) = \frac{a_0}{2} + \sum_{k=1}^{+\infty} A_k \cos(2\pi \frac{k}{T} x + \alpha_k), \tag{6}$$

where A_k - initial harmonic amplitude; $2\pi \frac{k}{T} x = \omega$ - circular frequency of harmonic oscillation; α - the initial phase of the oscillations; a_0 - Fourier coefficient of the function f .

3. Results and discussion

Calculation of the parameters of the transition process during hydraulic shock in the pressure cavity of the hydraulic cylinder implemented in the MathCAD medium is shown in figure 3.

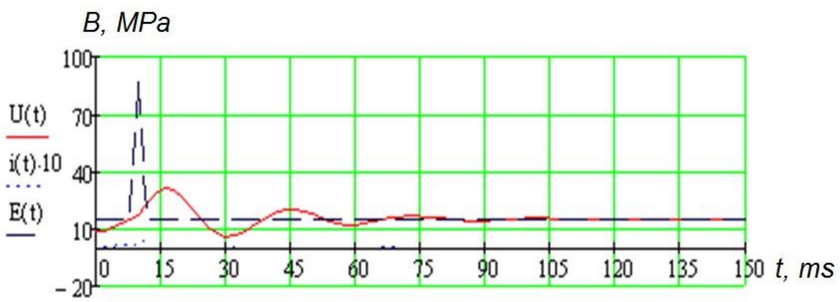

Figure 3. The parameters of the calculation of the transient during hydraulic shock in the pressure cavity of the hydraulic cylinder.

Under pulsed action, a pressure jump identical to hydraulic shock in the hydraulic cylinder is observed, after which a damped oscillatory process occurs, which can be described by known parameters [17-20].

For figure 4 shows the pressure jump in the hydraulic shock in the piston cavity of the hydraulic cylinder (solid line-not having the operating time of the hydraulic cylinder, dotted line-having the maximum operating time).

As you can see, the parameters of the transition process change significantly when the seals, piston and cylinder rod wear.

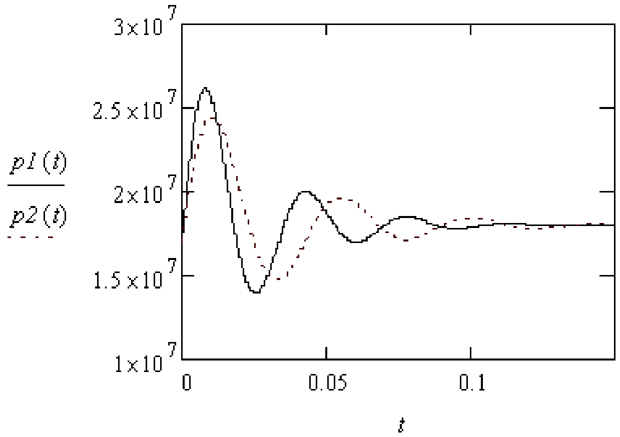

Figure 4. Dependence of pressure on time during hydraulic shock in the pressure cavity of the hydraulic cylinder without operating time and having the maximum operating time: *t* - time, s; *p1 (t)* and *p2 (t)* are the corresponding pressures in the pipe joint of the circuit, *Pa*.

By comparing the results of analytical modeling in the MathCad environment of pressure dynamics in the pressure cavities of the hydraulic cylinder (in accordance with the control mode), it was proved that the most informative control parameter is the logarithmic decrement of damped oscillations [16], which was adopted as a criterion for monitoring the technical condition of hydraulic cylinders.

The dependences of the logarithmic decrements of pressure fluctuations (δ) in the hydraulic cylinder from the pliability ($C_{pres.}$,) and hydraulic resistances ($R_{hydr.resist.}$) during seal wear are shown in figure 5. Analysis of these dependencies shows that the change in the structural parameters of the hydraulic cylinder, expressed in terms of compliance and hydraulic resistance, can be detected using the logarithmic decrement of oscillations.

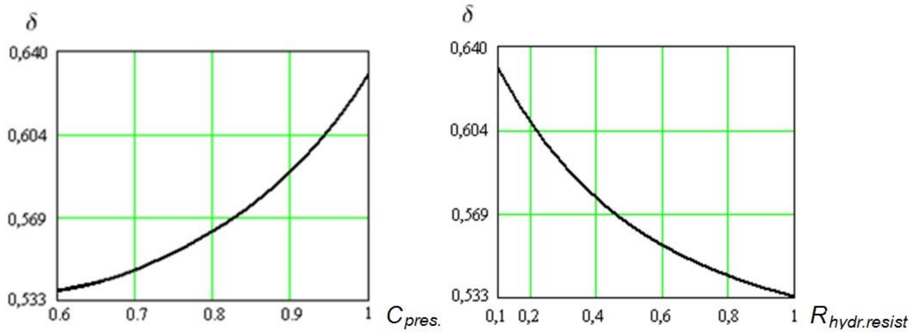

Figure 5. Graphs of changes in logarithmic decrements of pressure fluctuations (δ) in the piston cavity of the hydraulic cylinder during seal wear.

Based on the analysis of the pressure dynamics in the pressure cavity of the hydraulic cylinder, conducted using the MathCAD medium, it was found that the achievement of the limit value of the logarithmic decrement of oscillations is associated with the minimum values of pliability and hydraulic resistances, at which it becomes impractical to further operate the hydraulic cylinders.

Thus, the calculations of dynamic processes inside the hydraulic cylinder using the developed mathematical model allowed to justify the method of monitoring the technical condition of hydraulic cylinders.

The algorithm of the proposed method for monitoring the technical condition of hydraulic cylinders is as follows.

When the boom lifting or lowering the boom of the manipulator at the expense of stopping the piston at the end of its course there are fluctuations in fluid pressure as a result of hydraulic shock, the parameters of which are determined using known instruments, the deviation from reference values is judged on the technical condition of hydraulic cylinders. The use of the residual resource control method [12] makes it possible to determine the feasibility of further operation of hydraulic cylinders.

The difference between the developed oscillatory method for monitoring the technical condition of the hydraulic cylinder is that when controlling the hydraulic cylinders in the intended mode of operation, the influence on the accuracy of controlling the volume of liquid in the pressure cavities of the hydraulic cylinder is excluded. In hydraulic cylinders with damping devices at the end of the stroke, the instantaneous stop of the piston is carried out by means of automatic actuation of the shut-off valve before their inclusion in the work.

4. Conclusion

The studies carried out using the mathematical model of the hydraulic cylinder made it possible to determine the control parameter – the logarithmic decrement of damped oscillations.

When monitoring the technical condition of a specific element of the hydraulic drive in the functional mode of operation, it is necessary to install two shut-off valves per element, which act simultaneously. This will eliminate the influence of other elastic elements of the hydraulic drive.

When monitoring the technical condition of the hydraulic cylinder, it is recommended to use the extreme positions of the piston, which eliminates the impact on the accuracy of the diagnosis of the volume of the pressure cavity.

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