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Spectral method for monitoring the technical condition of hydraulic drives of forest harvester machines

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Abstract. Currently, in the forest industry, methods of test control of the technical condition of the elements of the hydraulic drive of forest harvester machines have been used, based on the creation of special impulse actions on the hydraulic drive in order to obtain transient characteristics, the analysis of which allows to determine their technical condition. However, these methods can only be used for maintenance or repair of machines. Analysis of the work performed to date shows that the task of developing and developing methods for monitoring the state of hydraulic drives of technological machines is an urgent task. This article presents the justification of the spectral method for monitoring the technical condition of hydraulic drives of forest harvester machines during the full life cycle, based on the control of its load when operating with woods.

1. Introduction

Currently, in the forest industry, methods of test control of the technical condition of the elements of the hydraulic drive of forest harvester machines have been used, based on the creation of special impulse actions on the hydraulic drive in order to obtain transient characteristics, the analysis of which allows to determine their technical condition [1].

However, these methods can only be used for maintenance or repair of machines. The analysis of the works performed to date [2-10] shows that the task of developing and developing methods for monitoring the state of hydraulic drives of technological machines is an actual problem.

This article presents the rationale for the method of monitoring the technical condition of the hydraulic drive in the operation of the machine, which allows you to determine the faulty elements during the processing of the object of labor forest harvester machine.

2. Materials and methods

The purpose of this work is to develop a spectral method for diagnosing hydraulic drives of forest harvester machines during the life cycle.

To do this, the following tasks are set: to justify the methodology for determining the loading of hydraulic drives of forest harvester machines using statistical dynamics methods, to determine the degree of influence on the controlled parameters of the diameter of the trunk of the treated, as well as the degree of wear of the hydraulic drive elements during operation of the machine.

The object of the study is the hydraulic drive of the device for cutting branches of the LP-30G machine widely distributed in the regions of Russia, subject to significant loads during operation, which accounts for the maximum number of failures.

On figure 1 presents a fragment of oscillographic recording of the hydraulic drive load, which shows that a random process occurs in it with a continuous change in the argument. Therefore, the characteristics of a random process were used in the processing of oscillograms.
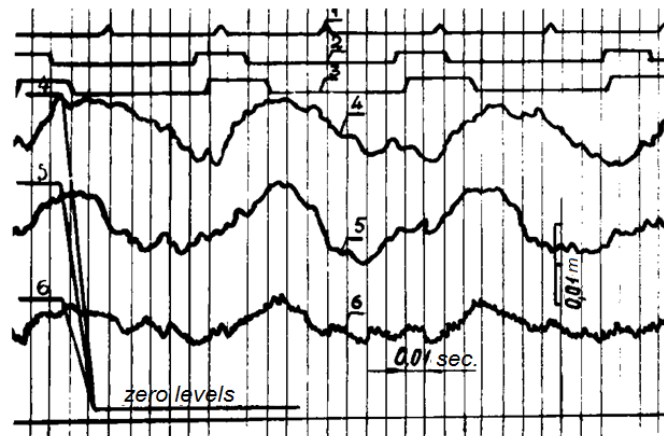

Figure 1. Pressure change in the hydraulic drive of the device for cutting branches of the machine LP-30B when processing wood with a diameter of 0,40 m: 1-3-timers of the speed of the pump shaft, the rotation angles of the left and right blocks of the dragging device; 4-6-pressure change in the pressure line of the side knives, the upper knife and the knives of the receiving head.

On the basis of the structural scheme of the hydraulic drive of the LP-30G machine, an equivalent design scheme is made, including all its elements-a pump, a hydraulic distributor, high-pressure hoses, a hydraulic motor.

The research used a five-mass calculation scheme, which fully reflects the real dynamic system of a typical hydraulic drive. The calculations take into account the elements of nonlinearity that characterize the elasticity (high-pressure hose, hydraulic valves).

The values of numerical statistical characteristics were determined by known dependencies [11-13].

When processing a continuous implementation of a random process, the values of the correlation function $R_{x(\tau)}$ are determined by the dependence [12]

$$R_{x(\tau)} = \frac{1}{T-\tau} \int_0^{T-\tau} x_{(t)} \cdot x_{(t+\tau)} \cdot dt,$$

(1)

where T - duration of continuous implementation of a random process; $x_{(t)}, x_{(t+\tau)}$ - centered function values $x(t)$ и $x(t+\tau)$.

In fact, when preparing the primary information, the ordinates of the random process are discretely read. In this case, the correlation function is determined by the expression

$$R_{x(\tau)} = \frac{1}{N-m} \sum_{i=1}^{N-m} x_i \cdot x_{i+m},$$

(2)

where N - number of ordinates discretely read from an oscillographic record of a random process; m - the number that determines the value of the shift along the abscissa axis $(m = 1,2,3,4,...)$;

x_i - the current value of the centered ordinate of the random process implementation at a time t_i; x_{i+m} - value of the centered ordinate of the process at the moment t_{i+m}.

When studying random processes in the elements of dynamic systems it is possible to use a normalized correlation function $\rho_{x(\tau)}$, which is defined by the expression

$$\rho_{x(\tau)} = \frac{R_{x(\tau)}}{R_{x(0)}}. \tag{3}$$

The experience of studying random processes [2-4] shows that in General, with the necessary degree of accuracy, the graph of the correlation function can be approximated by the expression

$$\rho_{x(\tau)} = \sum_{i=1}^{n} A_i \cdot e^{-\alpha_i |\tau|} \cdot Cos\beta_i \cdot \tau, \tag{4}$$

where α_i - the coefficients characterizing attenuation; β_i - coefficients characterizing the oscillatory process. In the case $\sum_{i=1}^{n} A_i = 1$.

In relation to the approximating expression (4) for the correlation function, the corresponding spectral density is determined by the relation

$$S_{(\omega)} = \frac{2}{\pi} \left[\sum_{i=1}^{n} \frac{A_i \cdot \alpha_i \left(\alpha_i^2 + \beta_i^2 + \omega^2 \right)}{\left(\omega^2 - \alpha_i^2 - \beta_i^2 \right)^2 + 4\alpha_i^2 \cdot \omega^2} \right], \tag{5}$$

where ω - the frequency of the process, s^{-1}.

Examples of graphs of normalized correlation functions of hydraulic drive loading, built on the results of calculation on a computer, are shown in figure 2-4, where a solid line denotes the function of the valve, the dash-dot line - hydraulic side knife, dash-dotted – cylinder top knife.

Graphs of normalized correlation functions are approximated with the required accuracy by an expression of the form

$$\rho_{x(\tau)} = A_1 \cdot e^{-\alpha_1 |\tau|} \cdot Cos\beta_1 \cdot \tau + A_2 e^{-\alpha_2 |\tau|} \cdot Cos\beta_2 \cdot \tau. \tag{6}$$

3. Results and discussion

The values of the approximation coefficients are shown in table 1.

Graphs of correlation functions characterize changes in the studied processes over time. Of particular importance are the characteristics of the frequency composition of the process - spectral density.

The spectral loading densities of the investigated hydraulic drive were determined by the formula

$$S_{(\omega)} = \frac{2}{\pi} \left[A_1 \frac{\alpha_1 \left(\omega^2 + \alpha_1^2 + \beta_1^2 \right)}{\left(\omega^2 - \alpha_1^2 - \beta_1^2 \right)^2 + 4\alpha_1^2 \omega^2} + A_2 \frac{\alpha_2 \left(\alpha_2^1 + \beta_2^2 + \omega^2 \right)}{\left(\omega^2 - \alpha_2^2 - \beta_2^2 \right) + 4\alpha_2^2 \omega^2} \right], \tag{7}$$

Analysis of graphs of normalized spectral densities (figure 5-7) shows that when processing the object of labor of different volumes there are two distinct zones of maximum values.

Table 1. The approximation coefficients of the normalized correlation functions

| The installation location of the sensors pressure (measuring point)	The coefficients of approximation					
	A_1	A_2	α_1	α_2	β_1	β_2
Diameter 0,30 m						
Hydraulically actuated valve	0,3	0,7	1,24	4,6	6,04	46,2
The hydrocylinder side of the knife	0,3	0,7	0,88	8,55	6,28	43,6
The hydrocylinder of the upper knife	0,35	0,65	0,32	5,87	6,54	43,6
Diameter 0, 35 m						
Hydraulically actuated valve	0,4	0,6	1,63	3,19	3,57	52,3
The hydrocylinder side of the knife	0,15	0,85	2,78	12,4	7,85	46,2
The hydrocylinder of the upper knife	0,3	0,7	1,61	6,16	4,61	49,1
Diameter 0,40 m						
Hydraulically actuated valve	0,27	0,73	8,73	5,28	9,8	65,4
The hydrocylinder side of the knife	0,30	0,70	8,70	8,97	9,50	65,4
The hydrocylinder of the upper knife	0,29	0,71	8,71	6,99	9,60	65,3
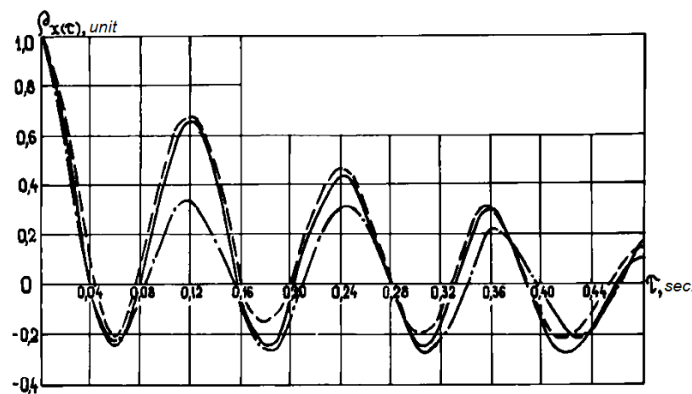
Figure 2. The normalized correlation function of the loading of the hydraulic drive when processing wood with a diameter of 0,40 m.
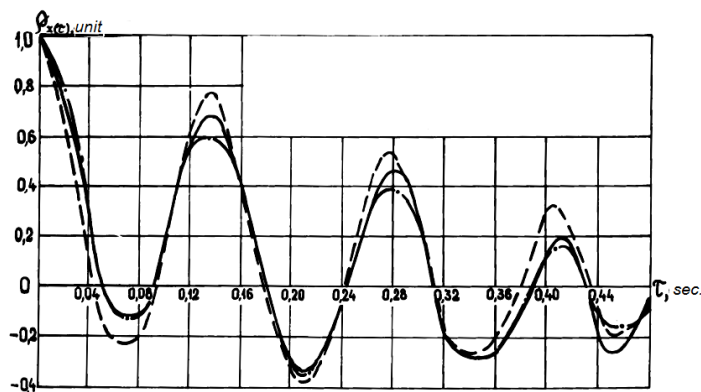

Figure 3. The normalized correlation function of the loading of the hydraulic drive when processing wood with a diameter of 0,35 m.
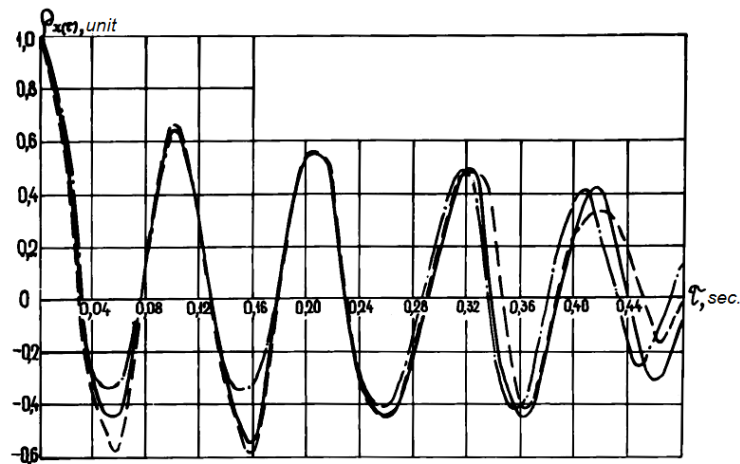
Figure 4. The normalized correlation function of the loading of the hydraulic drive when processing wood with a diameter of 0,30 *m*.
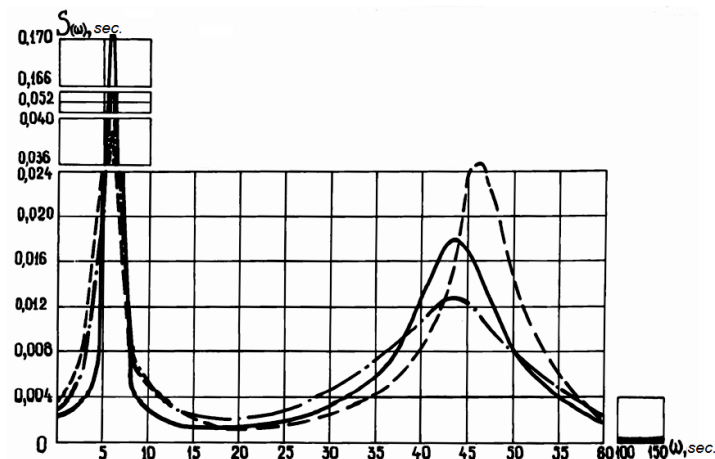

Figure 5. Normalized spectral density of the loading of the hydraulic drive LP-30G machines for processing wood with a diameter of 0,40 *m*.

The maximum spectral densities are shifted towards high frequencies with a decrease in the diameter of the trunk of the processed tree. When increasing the operating time of the machine (Fig. 8) there is a shift of maxima, with the high-frequency maximum shifting towards low frequencies, and the low-frequency one moving towards high frequencies.

This suggests that the maximum spectral densities obtained at certain values of the diameter of the processed tree are applicable as a control parameter for the technical condition of the hydraulic drive during the full life cycle.

Thus, the control of the parameters of the technical condition of the hydraulic drive, carried out using the method described above, can be considered as a justification for the method of monitoring the technical condition of the hydraulic drive of forest harvester machines.

The essence of the developed spectral method for monitoring the technical condition of the hydraulic drive is to determine the spectral loading densities of the diagnosed hydraulic drive when processing wood and compare it with the reference values of the spectral densities of the same type of hydraulic drive that does not have operating time.
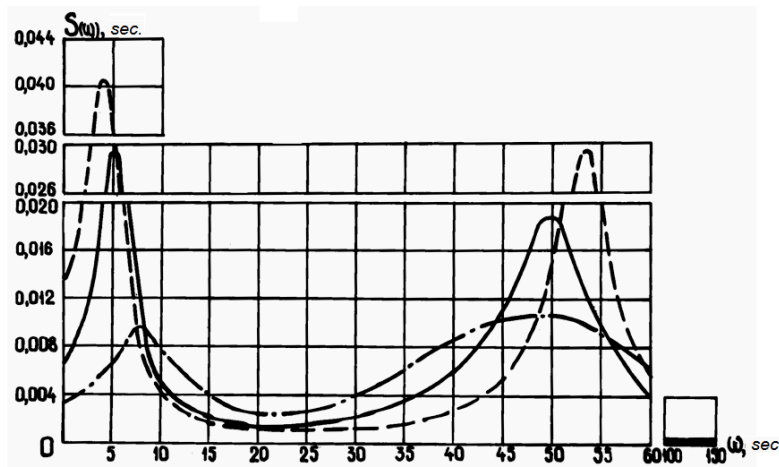
Figure 6. Normalized spectral density of the loading of the hydraulic drive LP-30G machines for processing wood with a diameter of 0,35 *m*.
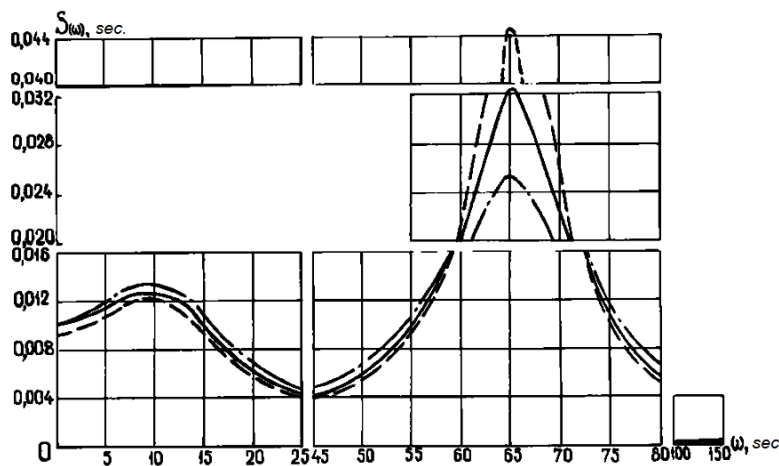

Figure 7. Normalized spectral density of the loading of the hydraulic drive LP-30G machines for processing wood with a diameter of 0,30 *m*.
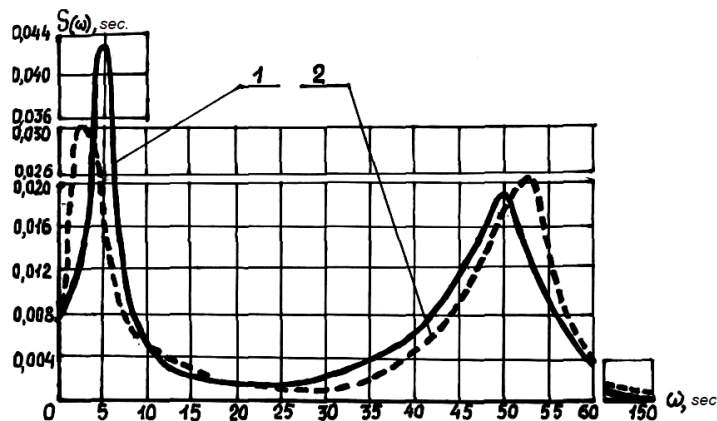

Figure 8. Normalized spectral loading densities of the hydraulic drive of the side knife at different operating hours: 1 - 1100 *hours*, 2 - 4500 *hours*.

The scientific novelty of the developed spectral method is to assess the technical condition of the hydraulic drive by the deviation of the maximum spectral loading densities of the hydraulic drive from the reference values. Comparison of the maximum spectral loading densities of the limit state hydraulic drive (intended for culling) with the diagnosed hydraulic drive makes it possible to determine the possibility of its further operation.

The developed method of monitoring the technical condition of hydraulic drives is intended for indirect control of the presence of faults in its elements when establishing the level of technical condition and assessing its suitability for further use.

4. Conclusion

A spectral method for monitoring the technical condition of hydraulic drives of forest harvester machines during the full life cycle, based on the control of its load when operating with wood, has been developed.

As control parameters, the maximum spectral loading densities of individual elements of the hydraulic drive can be used, by the displacement of which from the reference values determined at the beginning of operation of the hydraulic drive, it is possible to judge the technical condition of both individual elements and the hydraulic drive as a whole.

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