

## A Method for Functional Diagnosis of Hydraulic Drives of Forest Machinery

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### ABSTRACT

The reliability of forestry machinery is closely related to the labor intensity of its maintenance and repairs. Untimely diagnostics of failures entail additional financial losses due to machinery repairs and reduce the effectiveness of production. This paper describes a method for diagnosis of hydraulic drives of forest machinery in the process of their operation. A set of complementary methods relevant to the problem at hand was used to achieve the set goal, including analysis, abstract-logical, and analytical methods. The research generalizes the experience of Russian and foreign experts in the studied subject. In the course of experiments a lopping machine was tested. The developed technique is based on characteristics of the random process produced in the interaction of machine working parts with a tree. We obtained the normalized spectral density of loading the hydraulic drives of the tested lopping machine when processing trees under different operating time. By the rate of displacement of density peaks one can estimate the technical state of hydraulic drives. Thus, the use of the offered technique can increase the lifetime of machinery and reduce its wear.

### KEYWORDS

forestry machinery; wear; failure diagnostics;  
machine operation; hydraulic drives.

### ARTICLE HISTORY

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## Introduction

In order to improve the effectiveness of the wood industry, it is necessary to ensure a proper maintainability of forestry machinery (Edlund et al., 2013; Ismoilov et al., 2015; Matveev et al., 2016). Modern forestry machines, of both Russian and foreign manufacture, lack technical standard documents that indicate the duration of their maintenance (Westerberg and Shiriaev, 2015; Westerberg, 2014; Pirnazarov and Sellgren, 2015). This standard is a key index

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of machine maintainability. This creates problems for the rational operation of forestry machines (Robillard and Jorgensen, 2013; Sellgren et al., 2012; Fodor et al., 2016). This situation entails significant financial losses and poses a threat to the health of workers employed in the wood industry (Pirnazarov et al., 2012; Dudley et al., 2014; Leon and Benjamin, 2013). Thus, it is necessary to search for new techniques for diagnosing the operating condition of a machine, with a view to diagnosing failures in the mechanism before the machine breaks down.

Currently, the forest industry uses methods for testing the components of hydraulic drives of forestry machines (Robillard and Jorgensen, 2013; Sellgren et al., 2012), which are based on generation of special impulse actions on the hydraulic drive in order to obtain transient characteristics, which allows estimating their technical state (Drozdovsky, 1982; Lurie, 1970; Silaev, 1972). However, these methods can only be used at the periods of maintenance or repair of machinery.

This article considers the method for control a technical state of a hydraulic drive during the operation of a machine, which allows identifying malfunctioning unit during the processing of a tree.

### **Aim of the Study**

The purpose of this paper is to validate the method for diagnosis of hydraulic drives of forest machinery in the course of their operation.

### **Research questions**

How to describe a new method for determining the loading of hydraulic drives using the methods of statistical dynamics?

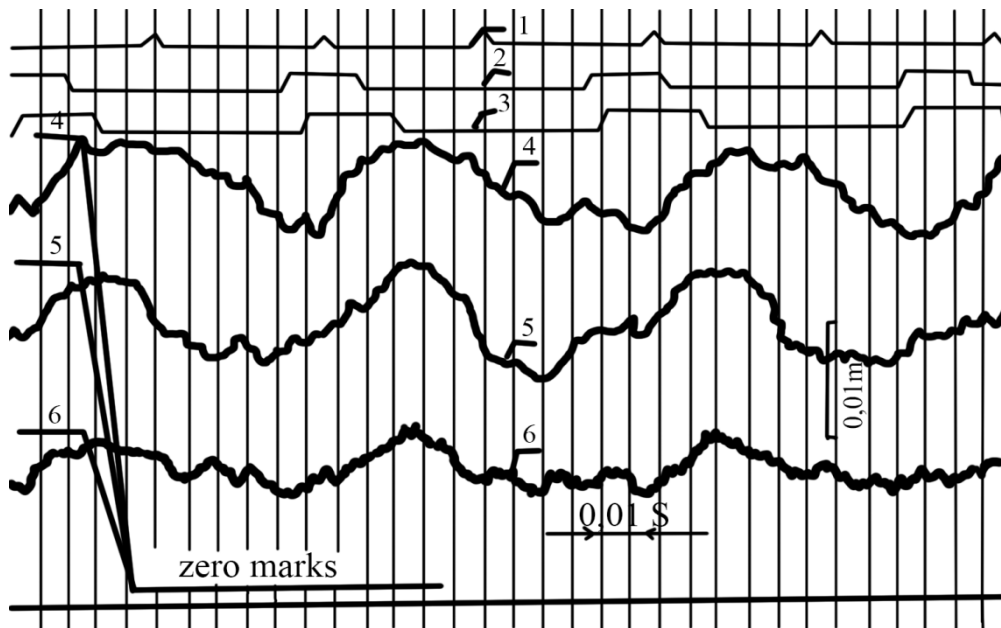
How to determine the rate of influence of the volume and species of a tree on the diagnostic parameters?

How to determine the rate of wear of hydraulic drive components in the operation of a machine?

### **Method**

The theoretical and methodological framework of the research includes the theory of regulation of sustainable development of timber production under diverse business patterns and integrative development of the wood industry, as well as studies of Russian and foreign specialists in the field of timber production. The conclusions were based on the generalization of Russian and foreign experience and the abstract-logical, analytical, and experimental methods.

For the experiments, a hydraulic drive of the delimeter LP-30G was selected, which were subjected to significant loads, and which had a large number of failures. Figure 1 shows a fragment of oscillographic recordings of the hydraulic drive loadings. This figure shows the random process with continuous change of the argument. Therefore, the random characteristics were used in the processing of an oscilloscope picture.



**Figure 1.** The change in pressure in the hydraulic drive of the lopping machine LP-30B in the processing of a tree with a diameter of 0.4 m: 1-3 - markers of the pump shaft speed and the rotation angles of the left and right blocks of a haul-through device; 4- 6 - pressure change in the pressure line of the side blades, the upper blade and receiving head blades

### Data, Analysis, and Results

On the basis of the block diagram of the hydraulic drive we made an equivalent design scheme, which included all its components such as pump, hydraulic valve, high pressure hoses, and hydraulic motor.

We used five-mass design scheme, which adequately described the real dynamic system of a typical hydraulic drive. The calculations took into account the elements of non-linearity, which characterize the elasticity (high pressure hoses, valves).

Numerical values of statistical characteristics were determined by the well-known formulas given in (Lurie, 1970; Silaev, 1972; Zukov and Kadolko, 1978).

When processing the continuous realization of the random process, the values of correlation function  $R_{x(\tau)}$  are defined by the formula (Lurie, 1970):

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

Where,  $T$  is the duration of the continuous realization of the random process;  $x(t)$ ,  $x_{(t+\tau)}$  are the centered values of the functions  $x(t)$  and  $x_{(t+\tau)}$ .

In fact, when preparing the primary information, it was carried discrete readout of the ordinates of the random process. In that case, the correlation function was given by

$$R_{x(\tau)} = \frac{1}{N-m} \sum_{i=1}^{N-m} x_i \cdot x_{i+m} \quad (2)$$

Where,  $N$  is a number of ordinates discretely read from the oscillographic recording of the random process;  $m$  is a number specifying the offset value on the horizontal axis ( $m = 1, 2, 3, 4, \dots$ );  $x_i$  is the current value of the centered ordinate of the realization of the random process in time  $t_i$ ;  $x_{i+m}$  is the value of the centered ordinate of the realization of the random process in time  $t_{i+m}$ .

One can use the normalized correlation function  $\rho_{x(\tau)}$  in studies of random processes in dynamic systems elements, which is determined by the expression:

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

Previous studies of stochastic processes (Lurie, 1970; Silaev, 1972; Zukov and Kadolko, 1978) showed that, in general, a graph of the correlation function with the required accuracy can be approximated by the expression:

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

where,  $\alpha_i$  is a coefficient characterizing the attenuation;  $\beta_i$  is the coefficient characterizing the oscillation process. In this case  $\sum_{i=1}^n A_i = 1$ .

With respect to the approximate Eq. 4 for the correlation function, the appropriate spectral density is given by:

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

Where,  $\omega$  is the process frequency,  $\text{s}^{-1}$ .

Examples of graphs of normalized correlation functions of the loading of the hydraulic drive, which were built on the results of computer calculations, are shown in Fig. 2, Fig.3, and Fig.4. These figures represent the loading curves of a hydro valve indicated by the solid line, a hydro cylinder of a side blade indicated by the dotted line, an upper blade cylinder indicated by the dash-dot line.

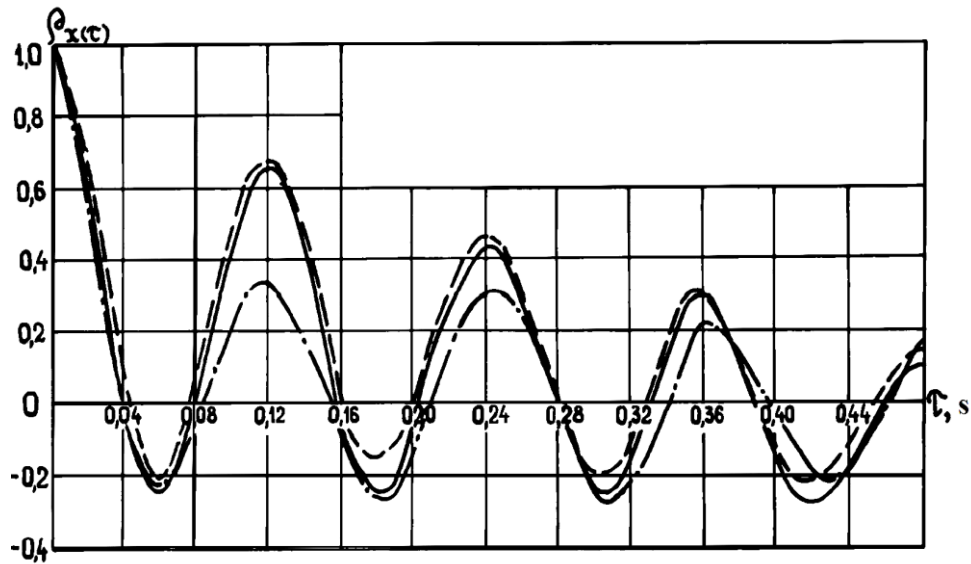
Graphs of the normalized correlation functions with the required accuracy were approximated by the following equation:

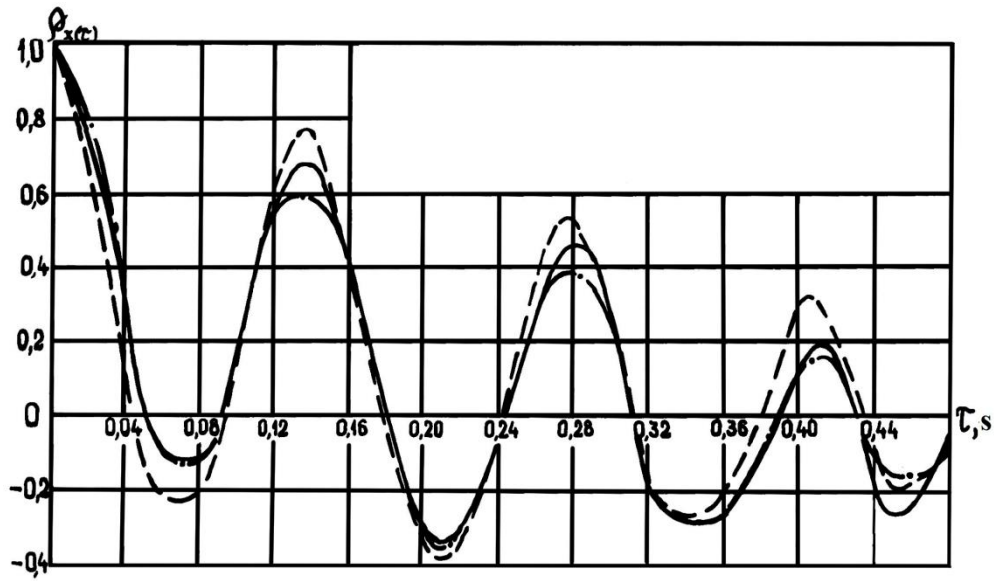
$$\rho_{x(\tau)} = A_1 \cdot e^{-\alpha_1 |\tau|} \cdot \text{Cos} \beta_1 \cdot \tau + A_2 e^{-\alpha_2 |\tau|} \cdot \text{Cos} \beta_2 \cdot \tau \quad (6)$$

Values of approximation coefficients are introduced in Table 1.

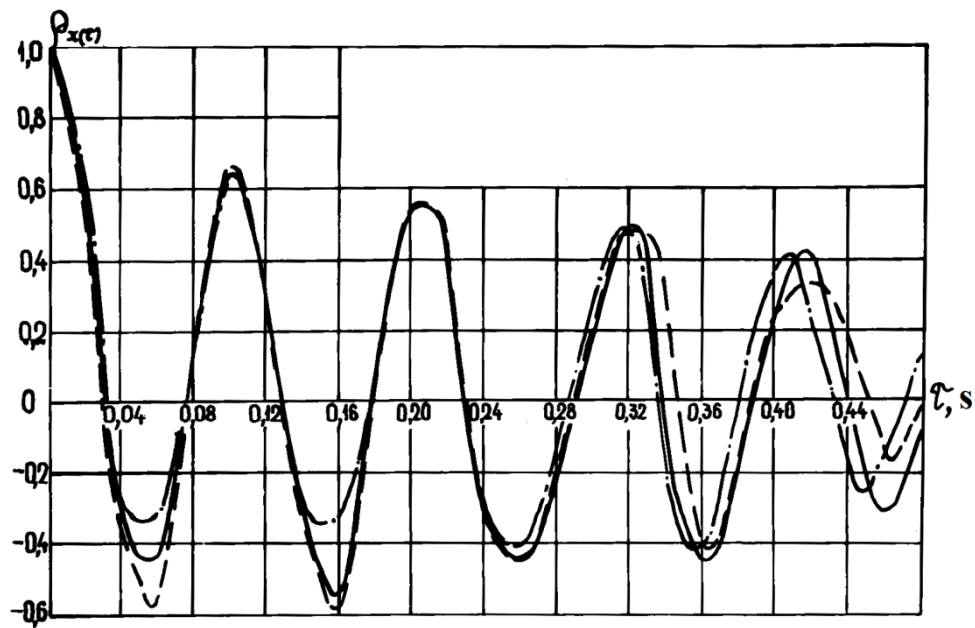
**Table 1.** Approximation coefficients of the normalized correlation functions

Placement location of a pressure sensor (measuring point)	Approximation coefficient					
	$A_1$	$A_2$	$\alpha_1$	$\alpha_2$	$\beta_1$	$\beta_2$
Diameter 0.30 m						
Hydro valve	0.3	0.7	1.24	4.6	6.04	46.2
Hydro cylinder of a side blade	0.3	0.7	0.88	8.55	6.28	43.6
Hydro cylinder of an upper blade	0.35	0.65	0.32	5.87	6.54	43.6
Diameter 0.35 m						
Hydro valve	0.4	0.6	1.63	3.19	3.57	52.3
Hydro cylinder of a side blade	0.15	0.85	2.78	12.4	7.85	46.2
Hydro cylinder of an upper blade	0.3	0.7	1.61	6.16	4.61	49.1
Diameter 0.40 m						
Hydro valve	0.27	0.73	8.73	5.28	9.8	65.4
Hydro cylinder of a side blade	0.30	0.70	8.70	8.97	9.50	65.4
Hydro cylinder of an upper blade	0.29	0.71	8.71	6.99	9.60	65.3


**Figure 2.** The normalized correlation functions of loading of the hydraulic drive at the processing of a tree with a diameter of 0.4 m



**Figure 3.** The normalized correlation functions of loading of the hydraulic drive at the processing of a tree with a diameter of 0.35 m

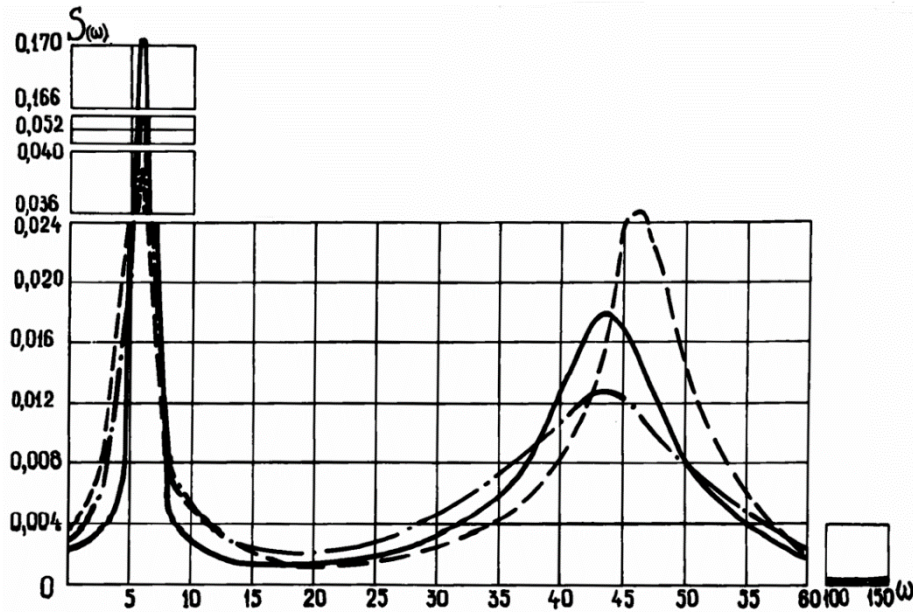


**Figure 4.** The normalized correlation functions of loading of the hydraulic drive at the processing of a tree with a diameter of 0.3 m

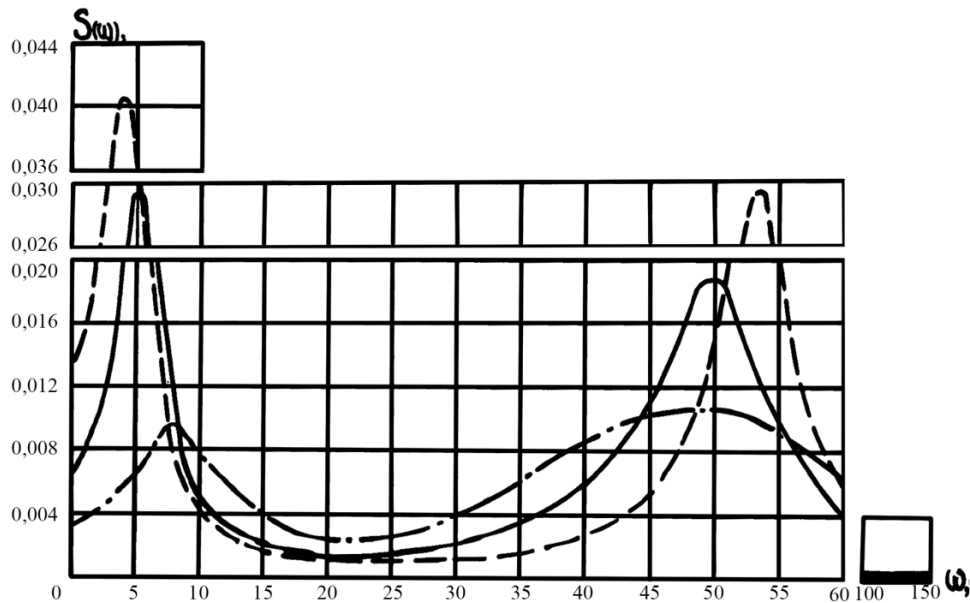
The graphs of correlation functions characterize the change of the studied processes in time. Of particular importance are the characteristics of the spectral density. (Fig. 5, Fig. 6, and Fig 7).

The spectral density of loading of the test hydraulic drive were found by the following equation:

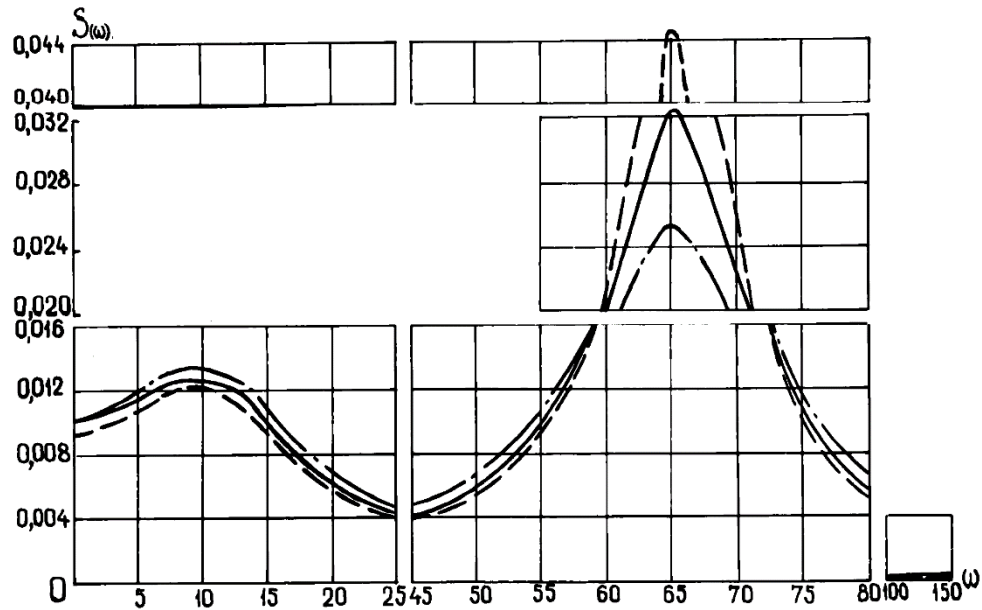
$$S_{(\omega)} = \frac{2}{\pi} \left[ A_1 \frac{\alpha_1 (\omega^2 + \alpha_1^2 + \beta_1^2)}{(\omega^2 - \alpha_1^2 - \beta_1^2)^2 + 4\alpha_1^2 \omega^2} + A_2 \frac{\alpha_2 (\alpha_2^2 + \beta_2^2 + \omega^2)}{(\omega^2 - \alpha_2^2 - \beta_2^2)^2 + 4\alpha_2^2 \omega^2} \right] \quad (7)$$



**Figure 5.** The normalized spectral density of loading of the hydraulic drive LP-30G at the processing of a tree with a diameter 0.4 m



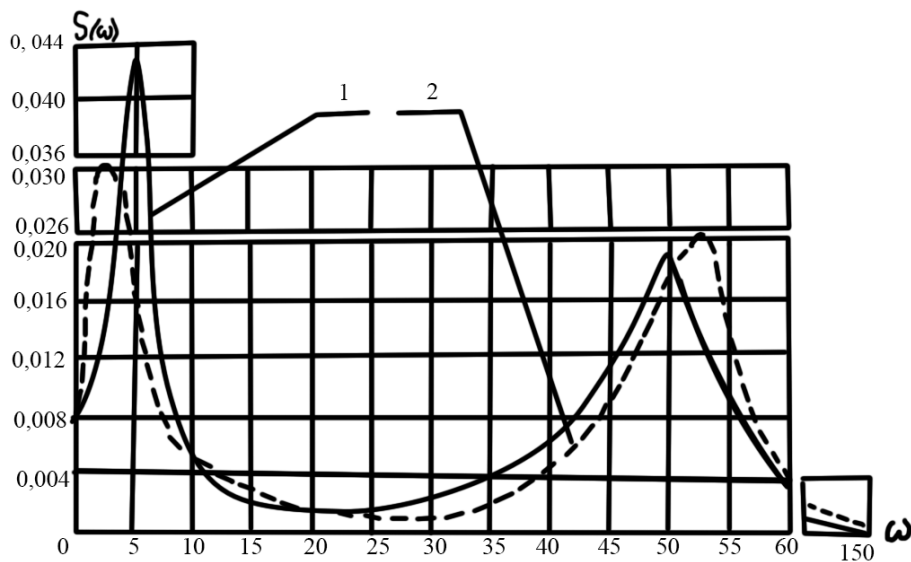
**Figure 6.** The normalized spectral density of loading of the hydraulic drive LP-30G at the processing of a tree with a diameter 0.35 m



**Figure 7.** The normalized spectral density of loading of the hydraulic drive LP-30G at the processing of a tree with a diameter 0.3 m

### Discussion and Conclusion

Analysis of the graphs of the normalized spectral density shows that, in the processing of a tree of various sizes, there are two distinct zones of maximum values. The peaks of the spectral density are shifted to higher frequencies with a decrease in size of a tree (Silaev, 1972). With an increase in the operating time (Fig. 8), it is observed a shift of peaks, as well.



**Figure 8.** The normalized spectral density of loading of a hydraulic drive's side blade for different operating time: 1 is for 1100 hour; 2 is for 4500 hours.



According to the obtained results we can conclude that, as a diagnostic parameter in determining the overall technical state of a hydraulic drive in the functional mode, we can use peaks of the spectral density obtained for the certain size of a tree.

Thus, the hydraulic drive research conducted using the technique described above allowed to validate a new method for functional diagnostics of a hydraulic drive.

The main point of the proposed method for control the overall technical state of a hydraulic drive is to determine the spectral densities of loading of the hydraulic drive diagnosed in the processing of a tree and to compare them with the reference values of the spectral densities of the same type of the hydraulic drive, which has no operating time.

The scientific novelty of the proposed method lies in the fact that the technical state of a hydraulic drive is estimated by the deviation of peaks of the spectral density of loading of a hydraulic drive compared with the reference values. Comparison of peaks of the spectral density of loadings of a hydraulic drive and its limit state (intended for rejection) allows you to determine the possibility of its further exploitation.

This method of functional diagnostics of hydraulic drives is purposed for the indirect troubleshooting of their elements in evaluation of the technical state and the level of their suitability for further use.

### **Implications and Recommendations**

In the course of operation of forest machines, a significant number of failures falls on their hydraulic drives. Moreover, the sudden failure of separate elements of a hydraulic drive (for example, high-pressure hoses) leads to a significant loss of the working fluid and machine downtime.

The present paper proposed the method for control the overall technical state of a hydraulic drive during the operation of a machine, which is based on the determination of its loading when processing trees. As the diagnostic parameters, it can be used peaks of the spectral density of loading of separate elements of a hydraulic drive, the deviation of which, relatively to the reference values, can be used for the evaluation of the technical state of separate elements as well as a hydraulic drive integrally.

Thus, the offered technique for diagnosing failures in forestry machines is capable of detecting failures in the mechanism before the mechanism itself breaks down. This enables extending the lifetime of the machinery and prevents significant expenditures on machine repairs.

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### **Disclosure statement**

No potential conflict of interest was reported by the authors.



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## References

- Drozдовsky, G.P, Pavlov, A.I. (1982) A technique for diagnosing elastic pipelines and a device for its implementation. A.S. No. 901676, B.I. 4.
- Dudley, N., Jeanrenaud, J. P., Sullivan, F. (2014). Bad harvest: The timber trade and the degradation of global forests. Routledge.
- Edlund, J., Keramati, E., Servin, M. (2013). A long-tracked bogie design for forestry machines on soft and rough terrain. *Journal of terramechanics*. 50(2), 73-83.
- Fodor, S., Freidovich, L., Vazquez, C. (2016). Practical trajectory designs for semi-automation of forestry cranes. ISR 2016: 47st International Symposium on Robotics; Proceedings of VDE VERLAG GmbH, 1-8.
- Ismoilov, A. et al. (2015). A comparison of novel chassis suspended machines for sustainable forestry. *Journal of Terramechanics*. 58, 59-68.
- Leon, B.H., Benjamin, J.G. (2013). A survey of business attributes, harvest capacity and equipment infrastructure of logging businesses in the northern forest. The Northern Forest Logging Industry Assessment. University of Maine, Orono.
- Lurie, A.B. (1970). *The statistical dynamics of agricultural machines*. L., Kolos, 371.
- Pirnazarov, A. et al. (2012). Predicting the mobility of tracked forestry machines operating on Nordic forest soil. 7th Americas Regional Conference of the ISTVS.
- Pirnazarov, A., Sellgren, U. (2015). Reduced testing and modelling of the bearing capacity of rooted soil for wheeled forestry machines. *Journal of Terramechanics*. 60, 23-31.
- Robillard, J.M., Jorgensen, C.K. (2013). Forestry machines with transverse engine and hydraulic system installation : USA patent 8579069.
- Sellgren, U. et al. (2012). Model-based development of machines for sustainable forestry. 12th European Conference of the ISTVS.
- Silaev, A.A. (1972). The spectral theory of vehicle cushioning. *M., Mechanical Engineering*, 192.
- Westerberg, S. (2014). Semi-automating forestry machines: motion planning, system integration, and human-machine interaction, *Robotics and control lab*, 56.
- Westerberg, S., Shiriaev, A. (2013). Virtual environment-based teleoperation of forestry machines: Designing future interaction methods. *Journal of Human-Robot Interaction*. 2(3), 84-110.
- Matveev, Y.V., Valieva, E.N., Trubetskaya O.V., Kislov, A.G. (2016). Globalization and Regionalization: Institution Aspect. *IEJME-Mathematics Education*, 11(8), 3114-3126.
- Zukov, A.V., Kadolko, L.I. (1978). Basic design of special forestry machines with regard to fluctuations. *Minsk, Science and Technology*, 264.