Mathematical model for defining peak loads in hydraulic manipulator’s joints

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Abstract. The main component which plays the key role in any cargo lifting machine is a hydraulic manipulator (HM). At the moment our factories manufacture a whole variety of HM, the main disadvantage of which is a short life span (3 to 5 years at full capacity). In order to increase the life span of a HM it is compulsory to continuously control peak load indicators during its utilization, therefore defining the optimal maintenance periods for the machinery. For controlling the technical condition of assembles and connections, non-dismantle methods of diagnostic are being used. The most perspective of them is the method of vibration measurement. The mathematical model of calculating peak shock loads, appearing if HM connections at the initial time and their relation to diagnosis parameter (vibration amplitude) is presented in the following article, frequency range of shock load is defined.

1. Introduction
One of the main tasks facing the forest complex is the creation of new innovative technologies of logging and wood processing production, manufacturing of modern domestic high-performance and reliable machines.

The main mechanism, on which the reliability and productivity of the load-lifting machine depends, is the hydraulic manipulator (HM). At present, our factories produce entire model lines of HM, the main drawback of which is a short service life ranging from three to five years with their full utilization.

Large manufacturers of modern equipment pay great attention to the development of a service network of machines. In order to ensure high performance of equipment, a proactive maintenance and repair strategy (M and R) has become increasingly popular in recent years.

The analysis conducted in [1] allows us to determine the proactive strategy of M and R as the most effective and purposeful for implementation in today's economic conditions. Pro-active strategy combines the advantages of preventive repair effects of the undertaken preventive system and information support of the decision-making processes typical for M and R regarding the technical condition of equipment.

The essence of M’s and R’s proactive strategy is to systematically eliminate the sources of defects, leading to premature failure of equipment. At the beginning the analysis and causes of occurrence is carried out to find the most frequently occurring defects and their influence on the inter-repair resource. Thus, all possible factors are considered that lead to development of various kinds of malfun-
tions. These factors are structural and technological impact on the environment, operating conditions, technical operation of equipment, qualification of personnel, degree of equipment wear, carrying out of M and R etc.

The proactive strategy of M and R is based on an estimation of a technical condition of the equipment that increases mechanism’s service life due to decrease in speed of development or elimination of nascent malfunctions at an initial stage of their occurrence; reduces expenses for carrying out of maintenance and R; reduces probability of emergency failures, raises factor of technical use of techniques.

The company “Lifting Machines” that is a manufacturer of hydraulic manipulators for various purposes provides the following maintenance intervals:
- maintenance of the M-1 every 50 hours;
- maintenance of the M-2 every 250 hours;
- maintenance of the M-3 every 500 hours;
- maintenance of the M-4 every 1000 hours.

The first failure time is set at 120 hours. The installed technical service life of the HM is determined at the rate of 6000 moto-hours or 3-5 years of operation depending on the intensity of HM use. In addition, according to the manufacturer’s data the presented technical resource of HM can be spent for 8-10 years at corresponding system of preventive maintenance.

At the same time, the manufacturer's regulations do not provide a major reduction of service intervals in case of a significant change in loads on the elements of the power structure of the HM or hydraulic system. Shock loads on the elements of the HM power structure at starting-brake or transition modes, gross violations of operating rules, overheating of liquid in the hydraulic system - all these factors directly affect the residual life of the M and should be a sufficient reason to reduce the maintenance intervals between services.

Moreover, the warranty policy of the manufacturer, as a rule, involves the analysis of failed elements and in each specific case, a specialist organizes a quite labor-intensive work to determine the possible factors that have influenced the premature failure in order to recognize the case warranty or non-warranty obligation.

In the presence of system, that monitors continuously the basic parameters influencing operational loadings, the decision-making process could be essentially simplified on recognition of case as the guarantee or not guarantee obligation.

For the end user, such monitoring system could also be useful allowing growth of service intervals in the absence of significant peak loads or overheating during the operation of the HM.

In the automotive industry, such systems have been used for a long time and have already gained the trust of both the manufacturer and the consumer. In particular, the vast majority of service intervals for internal combustion engines are evaluated by the dielectric permeability of the engine oil with a corresponding sensor, which detects the readings at each start of the engine. When oil is contaminated, oxidized and its additives are produced, the dielectric constant changes that leads to recalculation of the oil change interval.

Development of a full-fledged system of continuous monitoring of parameters is impossible without defining the criteria for evaluating the technical condition of the mechanism, so it is necessary to develop the theoretical and practical foundations of service organization, the optimal periods of service and HM prevention. For this purpose, modern methods of diagnosing machines are used. However, practically on all load-lifting machines, all mechanisms, except for HM, are subject to control.

Therefore, in order to increase the life cycle of the HM and the entire machine as a whole, it is necessary to apply the control of the technical condition of the HM in the process of operation and, thus, to determine the optimal periods of prevention for the mechanism, and thus find new methods of managing the technical condition of the mechanism. All listed above is directed on increase of reliability of HM, and increase of their service life that is an actual task.
The aim of the study is to improve the reliability of HM operations. This paper describes the scientific approach of the development of a mathematical model for the calculation of peak loads in the closed circuit on the example of HM VM-10L, used in the forest industry.

2. Methods and Materials
Currently there are conducted a lot of researches of loading a feller-buncher on different modes of their operations such as continuous and selective felling, dismantling of forest after windfall [2].

However, during hydraulic manipulator operation a short-term shock load arises at the initial moment, which renders the big influence on a technical condition of knots and co-stresses of HM. Then comes the established mode of operation of the HM, which is considered in detail in this paper [1].

In this article, the question of determining the impact load in terms of its influence on the technical condition of components and interfaces of the HM is considered.

In work [2] as the diagnostic signal defining a technical condition of the basic compounds of HM the amplitude of vibrations depending on shock loading in knots is defined.

To determine this load, let's consider a simplified scheme of stationary HM, presented in figure 1.

Figure 1. Simplified scheme of stationary HM.

where, 1 - swivel support device; 2 - boom; 3 - handle; 4 - grip with load; \( P_1 \) - load arising in the coupling grip-handle; \( P_2 \) - load perceived by the coupling of the handle-arm; \( P_3 \) - load arising in the pairing of the arm-resting device; \( P_4 \) - load perceived by the pairing of the arm-resting device; \( \alpha_1, \alpha_2, \alpha_3 \) - angles between the elements of the HM; \( l_1 - l_4 \) - length of the elements of the HM.

When lifting a load of mass \( m \) at the initial point of time, radial load \( P_1 \), causing impact pulse \( g_1 \), affects the grip support. In general, the impact pulse can be represented as [3].

\[
g = S f \left( \frac{F}{2} \right)^{0.5}
\]  

where, \( g \) is the shock pulse; \( S \) is the conjugation gap; \( f \) is the recovery factor; \( F \) is the conjugation load. Considering the HM's operation at the beginning of time, it should be noted that the main impact is on the interfacing of the handle and the arrow.

Figure 1 shows that:

\[
P_5 = [(P_4 + P_2)^2]^{0.5} = (P_4^2 + 2P_4P_2\cos \alpha_3 + P_2^2)^{0.5}
\]  

\[
\alpha_1, \alpha_2, \alpha_3 - \text{angles between the elements of the HM; } l_1 - l_4 - \text{length of the elements of the HM.}
\]
$P_2$'s load will be equal to

$$P_2 = P_1(l_1 + l_2)\sin \alpha_1$$

(3)

$P_4$'s load will be equal to

$$P_4 = P_3(l_4 + l_3)\sin \alpha_2$$

(4)

Then, from expression (1), we obtain the formula for the percussive impulse in the pairing of the boom-arm

$$g_5 = S_5 f \left[\frac{(P_4 + P_2)^2}{2}\right]^{0.5}$$

(5)

To determine the relationship between the amplitude of the vibration signal and the shock load, we use the expressions used in [3].

During the operation of the HM due to the changes in the gap values in the interfaces of the HM alters the value of the disturbing force. This happens because of the presence of amplitude modulation of the signal. Then:

$$g_5 = S_5 f [1 + \varepsilon \sin (\omega t + \phi)] \left[\frac{(P_4 + P_2)^2}{2}\right]^{0.5}$$

(6)

where, $\varepsilon$ - modulation factor; $\omega$ - modulation frequency; $\phi$ - modulation phase; $t$ - time.

The amplitude of the vibration signal will be equal to

$$A = \frac{1}{m} S_5 f [1 + \varepsilon \sin (\omega t + \phi)] \left[\frac{(P_4 + P_2)^2}{2}\right]^{0.5}$$

(7)

where, $m$ is the weight of the cargo.

3. Results and Discussion

Knowing the amplitude, mass and geometric dimensions of the HM can determine the frequency range in which the shock pulse occurs.

Initially, for the stationary variant the optimal position of the HM elements is fixed, the angles between the elements, their length for lifting the load of a given mass are determined, and the nominal frequency at which the impact occurs is calculated. Then experimentally establish deviations of angles and lengths of elements that can appear in conditions of work HM. In this way, the frequency range of the impact impulse generated is determined.

According to the results of studies conducted on the HM VM-10L, the frequency range is 0.5 - 3 kHz.

Thus, knowing the frequency and determining the amplitude of the vibration signal, it is possible to control the technical state of the HM couplings.

References

[1] Bobrovitskiy V I and Sidorov A V 2011 Improvement of the system of maintenance and repair of equipment in the conditions of centralization of the repair service of the enterprise (in Russian – Soverchenstvovanie sistemy TO I R oborudovaniya v usloviyax centralizacii remontnoi slugbi predpriatiea)Vibration of machines: measurement, reduction, protection. (Donetsk: Don-NTU), I(24) pp 23–28

[2] Gasimov G Sh and Alexandrov V A 2014 Dynamics of the felling and bundling machines (in Russian – Dinamika valohno-paketirujchih machin) (St. Petersburg: Polytechnic Units) p 244

[3] Martynov B G 2012 Fundamentals of diagnostics of the LZM (in Russian– Osnovy diagnostiki mekanizmov i agregatov LZM) (St. Petersburg: St. Petersburg State Technical University), p 100