Simulation of drive of mechanisms, working in specific conditions

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Abstract. This paper presents a method for determining the dynamic loads on the lifting actuator device other than the conventional methods, for example, ship windlass. For such devices, the operation of their drives is typical under special conditions: different environments, the influence of hydrometeorological factors, a high level of vibration, variability of loading, etc. Hoisting devices working in such conditions are not considered in the standard; however, relevant studies concern permissible parameters of the drive devices of this kind.

As an example, the article studied the work deck lifting devices - windlass. To construct a model, the windlass is represented by a rod of the variable cross-section. As a result, a mathematical model of the longitudinal oscillations of such rod is obtained. Analytic dependencies have also been obtained to determine the natural frequencies of the lowest forms of oscillations, which are necessary and are the basis for evaluating the parameters of operation of this type of the device.

1. Introduction

On June 1, 2015, the interstate standard [1] "Cranes. Principles of formation of design loads and load combinations" came into force; this standard sets out the general principles for determining the design loads and their combinations used for designing cranes and their mechanical elements.

However, the standard is not applied to the actuators of load-lifting devices mounted on ships and in mines, and there are elements of special technological equipment lifts and towers. Thus, the accepted standard calculation method does not offer the drives working in special conditions.

According to Section Projection of a socio-economic development of the Russian Federation for 2016 and the planning period of 2017 and 2018, developed by the Russian Ministry of Economic Development, the key directions of the state economic policy should include: the creation of conditions for increasing the efficiency of water biological resources extraction of hydrocarbons, as well as the expansion of the relevant scientific research. Obviously, to achieve this goal, it is necessary to have equipment, which will work under special conditions. Elements drive equipment may be located in different environments and experience a variety of loads, both from external factors and by loading variably STI (weight change and shape, resistance when moving an object, etc.). Therefore, development of a methodology for calculating this kind of drives of hoisting devices, other than those considered in the GOST 32579-2013, is an urgent task [1-4].
2. Materials and methods
Of course, covering a wide range of drive classes is very difficult, so at this stage of the learning
drives, operating under special conditions, examinations of deck based devices on sea vessels were
conducted. Their reliability criteria and machinery performance are stated in the Russian River and
Maritime Register of [2, 3], which, however, are not considered as non-stationary modes of drives.
A characteristic feature of the functioning of these devices is that they work with variable load in
multiple environments, in conditions of high vibration, high humidity, corrosive environments.
Approximately 40-60% of the time, the drives of these devices operate on unsteady modes. Moreover,
the time to failure is usually less than the average planned for 30-40% [4]. This is quite a serious
index, which shows that it takes an individual approach; the design is different from conventional
devices for data [5].

Let us consider the example of the calculation of deck machinery of marine vessel - windlass,
which is used for lifting anchors and creation of cable tension on mooring lines.

Modes of its drive operation differ significantly from each other: the speed of heaving up the
anchor chain varies from 0.12 to 0.70 m/s. The tension varies from 5 to 350 kN. Duration of the work
in different modes can take from 30 seconds to 30 minutes. During the operation of the windlass,
worm shaft bearings, the worm pair and main shaft may overheat; the gear teeth, forks and shift levers
may be broken or deformed.

In this case, the vessel is exposed to the external influence of wind, current, inertia arising from the
onboard or pitching of the vessel, which causes additional transverse vibrations on the operational
organ of windlass - gipsy.

The aim of research is to develop a method of determining dynamic loads on the actuators of load-lifting gears, other than those considered in GOST 32579-2013, for example, ship windlass.

For research of transverse oscillations of the originating warping drum on the winch, let us present
it as a rod of a variable section in the form of a truncated cone, height $h$ and mass per unit $m$ which
vary linearly:

$$h = h_0 \left(1 + \frac{x}{l}\right) \quad and \quad m = m_0 \left(1 + \frac{x}{l}\right),$$

where $h_0$ - section height, $x = 0$ and $m_0$ - linear mass $ho$ (fig. 1).

Assume that at undeformed state rod axis is rectilinear and align with mass axis of cross sections.
Herewith deviation of rod axis points under roll oscillation is carried out in one plane and are the "small" deviations given that occurring renovating forces are in limits of proportionality. Such
deviations are expressed by a function of two variables – coordinates $x$ and time $t$: $Y=y(x, t)$. The
kernel is influenced by distributed transverse load $f(x,t)$ and longitudinal force $P(x,t)$.

Then, using the variational principle of Ostrogradskii-Hamilton [6], the mathematical model of the
variable transverse cross section of the beam oscillations will be of the form:
\[
\begin{align*}
 f(x,t) &= -2m_0 \left( 1 + \frac{x}{l} \right) \frac{\partial^2 y}{\partial t^2} - 2 \frac{\partial P}{\partial x} \frac{\partial y}{\partial t} - 2 \frac{\partial^2 y}{\partial x^2} + 2 J_0 \frac{\partial^2 y}{\partial x^2 \partial t^2} \\
 &- \frac{12EJ_0}{l^2} \left( 1 + \frac{x}{l} \right) \frac{\partial^2 y}{\partial x^2} + l \left( 1 + \frac{x}{l} \right) \frac{\partial^2 y}{\partial x^2} + \frac{I^2}{6} \left( 1 + \frac{x}{l} \right)^2 \frac{\partial^4 y}{\partial x^4} = 0.
\end{align*}
\]

Let us consider the case when \( f(x,t) \equiv 0 \) and \( P(x,t) \equiv 0 \). As the simplest periodic solution of the received equations of free oscillations let us consider the so-called main oscillation in which function \( y(x,t) \) is changing with time by harmonic principle:

\[
y(x,t) = \varphi(x) \sin(\omega t + \alpha),
\]

where function \( \varphi(x) \) - the eigenmode, which for the rod has an infinite set and a certain value of natural frequency \( \omega \) corresponds to each form. To find the equation of eigenforms, let us substitute function \( y(x,t) \) and its partial derivatives in the obtained equation of the penciled oscillations of the rod:

\[
I^2 \left( 1 + \frac{x}{l} \right)^2 \varphi^{IV} + 6l \left( 1 + \frac{x}{l} \right) \varphi'' + 6 \varphi'' - k^4 \varphi = 0,
\]

where \( k^4 = \frac{p^2 m_0^2}{6EJ_0} \).

The resulting equation is a linear homogeneous quartic differential equation with variable coefficients. For the integration in quadratures, there is a methodical transition to an equation with constant coefficients \([7]\). In the defining function, \( z = f(x) = 2l \sqrt{1 + x/l} \).

According to the sufficient conditions of this technique \([8]\) for solutions in the quadratures quartic differential equation, it is necessary for the coefficients of the original equation to be interconnected to a certain function:

\[
\begin{align*}
 a_1(t) &= \frac{C_1}{4C_0} \sqrt[4]{a_0(t)} + \frac{3\dot{a}_0(t)}{2} ; \\
 a_2(t) &= \frac{C_2}{4C_0} \sqrt[4]{a_0(t)} + \frac{3C_1}{4\sqrt[4]{C_0}} \dot{a}_0(t) ; \\
 a_3(t) &= \frac{C_3}{4\sqrt[4]{C_0}} \sqrt[4]{a_0(t)} + \frac{C_4}{4\sqrt[4]{C_0}} \frac{\dot{a}_0(t)}{a_0(t)} - \frac{C_1}{8\sqrt[4]{C_0}} \frac{[\dot{a}_0(t)]^2}{a_0(t)^2} + \\
 &+ \frac{C_4}{4\sqrt[4]{C_0}} \frac{\ddot{a}_0(t)}{a_0(t)} - \frac{5}{16} \frac{\ddot{a}_0(t)}{a_0(t)} - \frac{10}{64} \frac{[\ddot{a}_0(t)]^2}{a_0(t)} - \frac{5}{16} \frac{[\ddot{a}_0(t)]^2}{a_0(t)^2} + \frac{\dddot{a}_0(t)}{4} , \\
 a_4(t) &= C_4. 
\end{align*}
\]

Adopting constant coefficients \( C_0 = l^2; C_1 = 0; C_2 = 0; C_3 = 0; C_4 = k^4 \), let us obtain the relevant equations with constant coefficients:

\[
\varphi^{IV}(z) - k^4 \varphi(z) = 0,
\]

there is a solution when using Krylov functions:
\[ S(z) = 0.5[ch(t(z-2l))+\cos(t(z-2l))], \]
\[ T(z) = 0.5[sh(t(z-2l))+\sin(t(z-2l))], \]
\[ U(z) = 0.5[ch(t(z-2l))-\cos(t(z-2l))], \]
\[ V(z) = 0.5[sh(t(z-2l))-\sin(t(z-2l))]. \]

Then obeying the integral at free point \( x = 0 \), which is given by:
\[ \varphi(z) = K_1S(t(z-2l))+K_2T(t(z-2l)). \]

Conditions on rigidly secured point \( x = l \) are expressed by equations:
\[ \begin{cases} 
K_1S\left(2l\sqrt{2}-1\right)+K_2T\left(2l\sqrt{2}-1\right)=0 \\
K_1V\left(2l\sqrt{2}-1\right)+K_2S\left(2l\sqrt{2}-1\right)=0 
\end{cases} \]

whence it follows that \( S^2-VT=0 \), or
\[ ch\left(2l\sqrt{2}-1\right)\cos\left(2l\sqrt{2}-1\right)+1=0. \]

According to table [6], let us find a root of equation \( 2l\sqrt{2}-1=1.875; \ 4.694; \ldots \)

Then for two first eigen forms, let us receive formulas for the determination of proper frequencies:
\[ p_1 = \frac{(1.875)^2}{4l^2(\sqrt{2}-1)^2} \sqrt{\frac{EI_0}{m_0}}, \]
\[ p_2 = \frac{(4.694)^2}{4l^2(\sqrt{2}-1)^2} \sqrt{\frac{EI_0}{m_0}}. \]

3. Conclusion

Results of the analytic solution can be used for the qualitative study of transient processes occurring in the marine deck equipment, namely - windlass.

In addition, the analytical expression was found that indicates the basic frequency of the transverse vibrations, which can be used in the design of the drive devices of this kind. Using the method proposed, solutions may not only determine the basic oscillation frequency, but also other characteristics of the oscillatory motion, in contrast to the approximate methods.

References
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