Configuring the algorithm of the load limiter with intermediate threshold

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Abstract. The problem of low quality of the operation of load capacity limiters is revealed due to incorrect tuning of its algorithm parameters. The technique of determining the parameters of the algorithm with an intermediate threshold is developed. The realization of the method is based on the information of the load and speed sensors of the lifting mechanism. Based on the methodology, the algorithm for automatic calculation of the intermediate threshold and the unconditional interdiction threshold is developed. For a real crane, the parameters of the rated capacity limiter algorithm are calculated. The comparison of the algorithm parameters with the values obtained by the empirical method is carried out. Conclusions are made about the applicability of the developed methodology.

1 Introduction

The basis of sustainable development of an industrial enterprise is ensuring the safety of technological processes realized at it [1]. To solve the problem of preventing accidents at hazardous production facilities that cause damage to the environment, human life and health, along with organizational measures, technical means of ensuring safety are used [2]. As applied to hoisting equipment, the main safety device is rated capacity limiter (RCL), which provides protection of the crane from lifting unregulated loads [3, 4].

The most modern RCL are devices OGSH-2 [5] and ONK-160M [6], realizing the algorithm with an intermediate threshold. Such an algorithm allows to fulfill the requirement of the normative documentation prohibiting the detachment from the base of the load by 25% higher than the nominal one.

Operation of RCL realizing the algorithm with intermediate threshold is correct only if its parameters (intermediate threshold and unconditional prohibition threshold) are set correctly. However, so far RCL manufacturers and specialized organizations have not developed a procedure of thresholds selection. For this reason, the quality of adjustment (device operation) depends on the qualification of the adjuster of safety devices.

In the work of N. Michalczyk [7] an attempt to develop an algorithm for tuning the intermediate threshold was made. The disadvantage of the developed method is the prediction of load by response time, which does not take into account the rigidity of the mechanical characteristic of the electric motor. This makes the method inapplicable for

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lifting mechanisms equipped with motors with phase rotor and additional resistors for speed control. Another factor reducing the accuracy of the method is the consideration of the stiffness of the rope suspension as a constant value. It is shown in [8, 9] that this parameter in the problems of determining the time of the pre-breakup phase of the lifting mechanism and moving the masses of rotating parts should take into account the zones of large and small nonlinearity of the function of the force in the rope suspension from its deformation.

The aim of the study is to develop a methodology for tuning RCL, which implements the algorithm with intermediate thresholds.

The objectives of the study are as follows: determination of criteria for tuning the intermediate threshold and the threshold of unconditional prohibition; justification of the set of primary information for tuning the RCL algorithm; experimental verification of the developed methodology.

2 Methods and Materials

Need to introduce an intermediate stop threshold $S_p$ is caused by the delay in the response of the control system (opening of contactors) and the response of the mechanical system (brake application, movement under the action of inertia forces). The duration of the response time depends on the dynamic parameters of the crane. The intermediate threshold must be set so that by the end of the response time (stopping the mechanism) the load on the mechanism does not exceed the maximum permissible value $S_{\text{1.25}\%}$ equal for overhead travelling cranes $1.25Q_{\text{nom}}$. On the other hand, reducing the intermediate threshold will result in no difference in the dynamic process between lifting a nominal load and a load of unacceptable mass by the time of stopping.

Since the motion of the mechanism is described by three computational cases during the response time (motor-driven motion, free coasting and braking), predicting the magnitude of the force at the moment based on time is not possible because it uses assumptions of equal-acceleration motion. Therefore, it is proposed to change from response time to path $x_r$ traveled by the rotating masses during the response time. In this case, the intermediate threshold will be determined by the formula:

$$S_p = S(x(S_{\text{1.25}\%})-x_r)$$ (1)

Obviously, the distance traveled during the stopping time when the actuator is operating at different initial speeds at the moment of the trip command will be different [10]. Therefore, if the lifting mechanism is equipped with a relay contactor control system realizing several speeds, the response path is determined for each of them. At the same time, the assumption is introduced that no switching between speeds occurs at the stage of rope tensioning.

To determine the response path, it is proposed to integrate the data of the speed sensor installed on the motor shaft by the formula:

$$x(t) = \frac{\pi}{60} \frac{D}{a \cdot u} \int n(t) \, dt - \frac{S(t)}{c_b}$$ (2)

$D$ – drum diameter [m];
$a$ – chain hoist ratio;
$u$ – gear ratio;
$n(t)$ – time dependence of the motor shaft frequency (1/sec);
$S(t)$ – time dependence of the force in the rope suspension;
$c_b$ – crane bridge stiffness.
To determine the intermediate threshold, we use the experimental characterization of the force in the rope suspension from its deformation, obtained by the method described in the patent [11]:

\[ S(x) = -8.285 \times 10^4 x^3 + 4.208 \times 10^3 x^2 + 2143x + 174 \]  \hspace{1cm} (3)

From the strain value corresponding to the force 1.25\( Q_{\text{nom}} \), postpone the response path value \( x_r \) for each artificial motor characteristic. In this case, the threshold of the unconditional prohibition is within the range from the maximum dynamic load when lifting a nominal load to \( S_{125\%} \). The phases of determining the response path, intermediate threshold and unconditional ban threshold are depicted in Fig. 1 a, b and c, respectively.

![Fig. 1. Illustration of the methodology for setting the parameters of the RCL algorithm with an intermediate threshold: a - determination of the displacement of the masses of rotating parts during the response time; b - determination of the intermediate threshold based on the experimental dependence of the force in the rope suspension on its deformation; c - determination of the threshold of unconditional prohibition. Radd is the value of added resistance [Ohm]; \( S_{\text{c.t.}} \) – unconditional prohibition threshold [N].](image)

Experimental verification of the method of tuning the RCL algorithm was carried out on a double-girder overhead crane KMG-201, installed in the laboratory of the Department of "Lifting and Transportation Systems" Bauman Moscow State Technical University, the main parameters of which are shown in Table 1.

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<tr>
<th>Table 1. Experimental setup parameters.</th>
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<td>Crane load capacity, t</td>
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<tr>
<td>2</td>
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<tr>
<td>Nominal torque, Nm M(<em>{\text{nom}})/M(</em>{\text{nom}})</td>
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The algorithm for tuning the RCL parameters is realized on the experimental device OGSh-5R. To obtain primary information, the device is equipped with a superimposed strain gauge sensor DNA-2 and analog-to-digital converter PTC-2(7.0.4), speed sensor FC-03. The microprocessor unit is based on a single-board computer Raspberry Pi 4B.

3 Results

Fig. 2 shows synchronized graphs of the force in the rope suspension and speed of the electric motor, describing the dynamic process of operation of the lifting mechanism when the command to disconnect upon reaching the load corresponding to the rated load is given.

According to the graph of motor speed by formula (2) the response path is determined, the value of which is as follows $x_r=0.0129 \text{ m}$. According to the graph of force in the rope suspension from deformation by formulas (1) and (3), the value of the intermediate threshold of triggering was determined as amounted to $0.27Q_{\text{nom}}$.

Fig. 3 shows the dynamic process when a nominal load is lifted and a stop command is given at the intermediate threshold.
Fig. 3. Determining the threshold for an unconditional interdiction.

The achieved value of the maximum dynamic load, which amounted to $1.13Q_{\text{nom}}$, is the lower boundary of the unconditional prohibition threshold. The upper limit is $1.25Q_{\text{nom}}$.

4 Discussion

The obtained value of the intermediate threshold is compared with the values obtained for the same crane empirically in [12]. The calculated value $0.27Q_{\text{nom}}$ is at the lower end of the range $[0.27Q_{\text{nom}}...0.35Q_{\text{nom}}]$, the conditions of operability of authorization of lifting of nominal load and prohibition of lifting of loads were met at $1.25Q_{\text{nom}}$. This result is obtained due to the assumption of plane-parallel motion of the load at the moment of its detachment from the base. However, the real load has a displacement of the center of mass relative to the vertical axis passing through the point of suspension of the load. When the near-nominal force is reached, the center of mass of the load moves, but the contact rib with the base is maintained. Thus, tightening of the pre-breakaway stage of the lifting mechanism operation allows to keep the RCL operability at the increase of the intermediate threshold.

The developed technique differs from the algorithm [7] by the requirement to expand the number of sources of primary information used by RCL, speed sensor, which is justified by the need to calculate the characteristic of the force in the rope suspension from its deformation and the path traveled during the response time.

5 Conclusions

The paper proposes a technique for determining the parameters of the RCL algorithm (intermediate threshold and threshold of unconditional prohibition). By following the methodology, it allows to guarantee the reliability of fulfillment of the requirements of regulatory documentation to RCL.

The algorithm of RCL parameters setting was developed taking into account the possibility of its subsequent automation, which will reduce the labor intensity of this process and the time of crane withdrawal from the maintenance of the technological process.
The developed device, realizing the presented algorithm, has experimentally confirmed its operability.

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