ПРИКЛАДНА МЕХАНІКА

DOI: 10.31319/2519-2884.48.2026.3
UDC 621.874.7

Kabakov Anatolii, Candidate of Technical Sciences, Associate Professor of the Department of Industrial Engineering
Dniprovsky State Technical University, Kamianske

Кабаков А.М., к.т.н., доцент, ORCID: 0009-0008-3948-8687, e-mail: kabakovanatoly@gmail.com
Дніпровський державний технічний університет, м. Кам’янське

DRIVE CONTROL OF THE HOISTING MECHANISM

The goal of the research is to develop devices for drive control of load hoisting, in which the drive is disconnected not based on the level of dynamic loads, but on the predicted impermissible load mass. This is achieved by measuring the average acceleration speed of the mechanism on the drive's steady-state mechanical characteristic. Since the rate of load increase in the rope, given an unchanged acting force, is inversely proportional to the mass of the lifted load, this allows for control of the drive motor during the initial hoisting stage. This prevents the development of significant overloads in the crane's power elements.
Keywords: *drive control; hoisting mechanism; load hoisting; dynamic loads; drive motor.*

Метою дослідження є розробка пристроїв для керування приводом підйому вантажу, в яких відключення приводу здійснюється не за рівнем динамічних навантажень, а за прогнозованою неприпустимою масою вантажу шляхом вимірювання середньої швидкості розгону механізму на стаціонарній механічній характеристиці приводу. Оскільки швидкість наростання навантаження у канаті при незмінній діючій силі обернено пропорційна масі вантажу, що піднімається, це дозволяє здійснювати керування приводним двигуном на початковій стадії підйому. Це запобігає розвитку значних перевантажень у силових елементах крана.
Ключові слова: *керування приводом; механізм підйому; підйом вантажу; динамічні навантаження; привідний двигун.*

Problem’s Formulation

One of the ways to protect the crane from dynamic loads is by using Load Capacity Limiters (LCLs). The goal of installing LCLs is to protect the metal structures and elements of the crane from:

1. Excessive plastic deformations;
2. Loss of stability (for metal structures);
3. Brittle failure;
4. Fatigue damage.

For Load Moment Limiters, protection of the crane against overturning is also included.

Preventing damage according to points 1, 2, and 3 requires limiting the maximum acting loads regardless of the duration of their application. To prevent fatigue damage to mechanism elements (shafts, axles, gear transmissions), loads acting continuously during operation should be limited, as these elements receive many tens of load cycles per crane operating cycle.

Protecting metal structural elements from fatigue failure requires limiting the stresses acting within them.

However, the vast majority of existing LCL designs are not truly limiters in the literal sense, because due to constructive and functional features, the limitation is carried out not by the magnitude of the load mass, but by a certain limiting level of dynamic loads at the moment of hoisting, and to a lesser extent, it depends on the mass of the lifted load. Furthermore, the currently applied method of controlling the hoisting mechanism when the limiter is triggered involves only switching off the motor and applying the brake. However, dynamic analysis of the LCL actuation process leads to the conclusion that a simple motor cut-off, combined with the rotating masses of the hoisting mechanism still in motion when the LCL trips, can lead to the load breaking free from the ground.

The machine remains overloaded until the crane operator lowers the load to the ground. Thus, existing LCL systems limit the operation of the hoisting mechanism primarily based on the level of dynamic loads and do not provide reliable protection against crane overload caused by excessive load mass.

The LCL is built using microprocessor technology, which is currently widely used in LCL construction.

Analysis of recent research and publications

There is a great variety of Load Capacity Limiter designs, which are classified by the nature of the sensors used as mechanical, hydraulic, electrical, and combined (e.g., electromechanical) [1, 2, 3]. They can be installed on the measuring block, the crane's metal structure, the hoist drum support, etc.

However, due to the constructive and functional features of the vast majority of designs, the limitation is carried out not by the magnitude of the load mass, but by a certain limiting level of dynamic loads at the moment of hoisting, which are determined primarily by the dynamics of the hoisting mechanism and are less dependent on the mass of the lifted load [4].

Furthermore, the activation of the limiter only leads to switching off the motor and applying the brake. Although this prevents the crane from operating with a load of an unacceptably large mass, it does not solve the problem of protecting the crane's elements from dangerous overloads, because with a simple motor cut-off, the lifted load, under the action of the kinetic energy of the rotating masses of the hoisting mechanism, will not detach from the ground and remains in a lifted state for a long time [5, 6].

Formulation of the study purpose

The goal of the research is to develop devices for drive control of load hoisting, where the drive is disconnected not based on the level of dynamic loads, but on the predicted impermissible load mass. This is achieved by measuring the average acceleration speed of the mechanism on the drive's steady-state mechanical characteristic.

Since the rate of load increase in the rope, given an unchanged acting force, is inversely proportional to the mass of the lifted load, this allows for control of the drive motor during the initial hoisting stage. This prevents the development of significant overloads in the crane's power elements.

Presenting main material

To eliminate the above-mentioned drawbacks, a device for controlling the drive of the hoisting mechanism has been developed, the functional diagram of which is shown in Fig. 1. In this device, the LCL actuation is carried out not based on the level of dynamic loads, but on the predicted load mass.

The reliability of operation of hoisting and transport machines, along with the reduction of dynamic loads in transient regimes, is also ensured by introducing automatic Load Capacity Limiters (LCLs) into the hoisting mechanism control scheme, which prevent the lifting of an excessively large mass of load.

Meanwhile, currently mass-produced bridge cranes are equipped with LCLs, which, due to their structural and functional features, implement the limitation not by the magnitude of the load mass, but by a certain limiting level of dynamic loads at the moment of hoisting. These loads are determined primarily by the dynamics of the hoisting mechanism and to a lesser extent depend on the mass of the lifted load. Furthermore, the currently applied method of controlling the hoisting mechanism when the limiter is triggered consists of only switching off the motor and applying the brake. At the same time, although the operation of the crane with an unacceptably large mass of load is prevented, the task of protecting the crane's elements from dangerous overloads is not solved. This is because, with this motor cut-off, the lifted load, under the action of the kinetic energy of the rotating masses of the hoisting mechanism, manages to break away from the base and remains in a lifted state for a long time.

The aforementioned drawbacks are eliminated by the device for controlling the drive of the hoisting mechanism of the lifting equipment.

In this device, the drive is disconnected not based on the level of dynamic loads, but on the predicted impermissible load mass by measuring the average acceleration speed on the steady-state mechanical characteristic of the drive. Since the speed of load increase in the rope, given an unchanged acting force, is inversely proportional to the mass of the lifted load, this allows for control of the drive motor during the initial hoisting stage. This prevents the development of significant overloads in the crane's power elements.

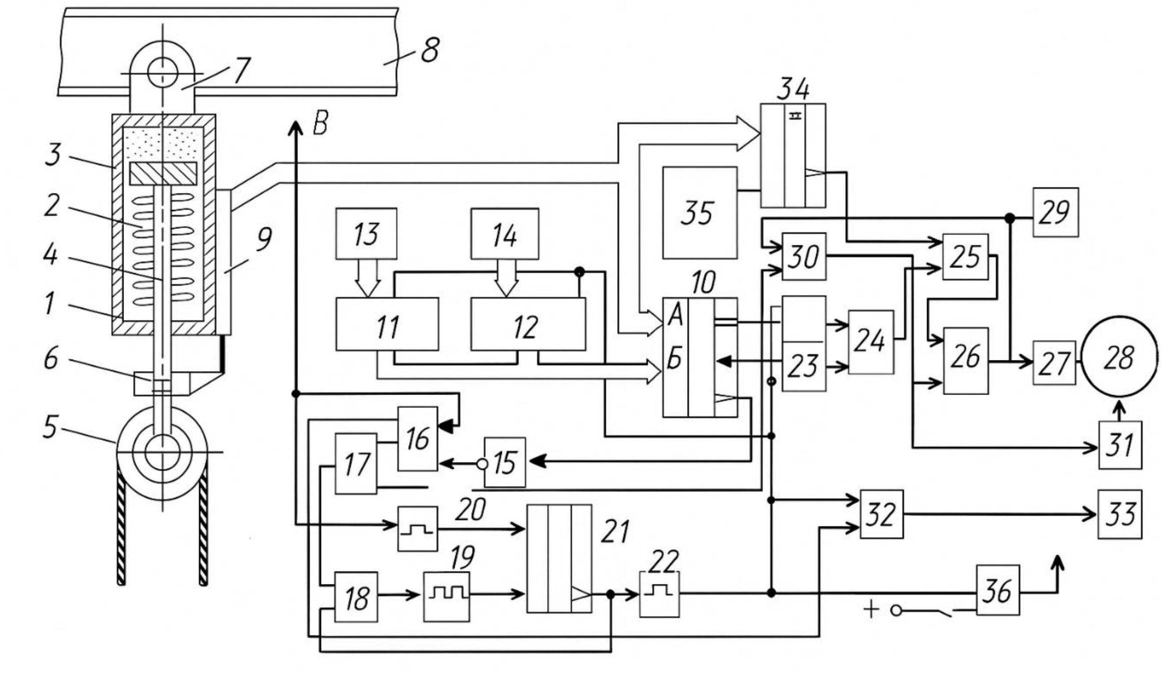

Fig. 1. Functional diagram of the device for controlling the drive of the crane hoisting mechanism

The mechanism control device for the hoisting drive of the lifting equipment, for example, a hoist trolley, contains a cylindrical body I, inside which an elastic element 2 is located, resting on a washer 3 with a rod 4, which is connected to the compensating block 5 of the block-and-tackle via a hinge 6.

Body I is suspended from the frame of the hoist trolley 8 with the help of a bracket 7. A digital load sensor 9, which is connected to the rod 4, is installed on the body I. A deformation converter of the elastic element and a drive control system (see Fig. 1) are used as the sensor.

The device operates as follows:

In the initial state (without a load), the rope tension force is close to zero, the elastic element 2 is not loaded, and the device does not affect the operation of the hoisting mechanism. When the operating mode setter for the hoisting mechanism drive motor is switched to the position of the "softest" mechanical characteristic of the drive, a high logic level is established at one of the inputs of element 16, which serves as the device enabling command. At the same time, a digital code is present at input B of the digital comparator 10. This code is set from the output of the bus former 11, at whose input an analogous code is established by the position of the switches of the setter 13, corresponding to the deformation of the elastic element 2 under the action of the force in the rope (≈1–5%) of the nominal value. At this moment, the rope is not loaded, and the code at input A from the output of the digital sensor 9, which is proportional to the deformation of the elastic element 2 under the action of the force in the rope, turns out to be less than the code at input B. The signal from the "greater than" output of the comparator 10, via the inverter 15, allows the actuation of element 16. The signal from the output of element 16 sets the trigger 32 to a state that engages the relay 33 of the controller blocking, which prohibits switching to other drive characteristics.

As the rope tension increases, the code at input A will increase, and upon reaching equality with the code at input B, a signal will appear at the "equal to" output of the comparator 10, which permits the actuation of element 17. The signal from the output of element 17 starts the control timer, which precisely sets the time for measuring the speed of the force increase in the rope. This time is determined by the frequency of the generator 18, chosen so that the overflow of the counter 21 occurs in 0.05–0.1 seconds. After this time has elapsed, the one-shot vibrator 22 is started. The signal from its output prohibits the issuance of the code to the common bus from the former 11 and permits the setting of the code from the output of the former 14, at whose input a code is set from the setter 14, determining the value of the forces in the rope that corresponds to the lifting mode of the limit mass load. If at this moment it turns out that the code value at input A is greater than the code at input B (load mass is less than the maximum permissible), a signal will be set at the "greater than" output of comparator 10, which prohibits the enabling of element 16 during any actions or manipulations of the controller until the load is removed. This prevents false actuation of the device.

The signal from the output of the one-shot vibrator 22 returns the trigger 32 to its initial state, which engages the relay 33 blocking the setter, permitting the enabling of subsequent setter stages.

If input A is equal to or less than the code at input B (load mass is equal to or greater than the maximum permissible), the rate of force increase in the rope with such a load is always less than (?) the signal from the "less than" or "equal to" output of comparator 10 at the moment the signal appears from the output of the one-shot vibrator 22, through elements 23, 24, 25, sets the trigger 26 to a state that engages the engine redundancy relay 27. This means that hoisting is prohibited based on the operation of predicting the lifting of an unacceptably large load mass. When the engine redundancy 28 is activated, the loads in the rope decrease, the digital code at input A of the comparator 10 also becomes smaller, and upon reaching equality with the code at input B, which at this moment is determined by the code of the bus former 11, the signal from the "equal to" output of comparator 10, in the presence of a high logical level from the output of the trigger 26, sets a high logical level at the output of element 30, which ensures the return of trigger 26 to its initial state, and returns the engine redundancy relay 27 to its initial state, and the brake is engaged via relay 31. The prohibition of load hoisting is indicated by an indicator.

Simultaneously, a comparison operation takes place between the number at input A from the output of the digital sensor 9 and the code at input E from the output of block 35 of dynamic load setpoints in the digital comparator 34. If the code at input A is greater than the code at input E, which determines the permissible level of dynamic loads, the signal from the "greater than" output of comparator 34 performs an analogous control of the hoisting mechanism drive via element 30, ensuring additional protection for the mechanisms and metal structures.

Operational adjustment of the device is ensured by means of an auxiliary trigger 36, the signal from whose output prohibits the change of state of the digital sensor 9.

The hoisting of a load of the limit mass is performed, and at the moment the one-shot vibrator 22 is switched on, the trigger 36 blocks the reception of information from the digital sensor 9, the content of which corresponds to the load capacity limitation code value, determines the code at input A of comparator 10, and sets the analogous code at the output of the setter 14.

The device can be implemented using both digital and microprocessor elemental base technology.

Thus, the developed device prevents the hoisting of a load that causes crane overload. At the same time, the lifted load remains on the ground, and loads from it are not transmitted to the elements of the hoisting mechanism and the crane's metal structure.

Conclusions

The actuation of the limiter depends not only on the level of dynamic loads, but also on the impermissible load mass, which is predicted by measuring the average acceleration speed of the mechanism, taking into account the steady-state mechanical characteristic of the drive. Since the rate of load increase in the rope, given an unchanged acting force, is inversely proportional to the mass of the lifted load, this allows for control of the drive motor during the initial hoisting stage, preventing the development of significant overloads in the crane's power elements. These devices can be installed on cranes of any design, operate in automatic mode according to their own algorithm, and are compatible with the control systems of robotic hoisting and transport machines.

References

[1] Ivanchenko F.K. (2008). Pidiomno-transportni mashyny: Navchalnyi posibnyk. [Lifting and transport machines: textbook]. Kyiv: Vyshcha shkola, 413 p. [in Ukrainian].

[2] Bondariev O.I. et al. (2009). Pidiomno-transportni mashyny: Rozrakhunky pidiimalno-transportuvalnykh mashyn. [Lifting and transport machines: Calculations of lifting and transporting machines]. Kyiv: Vyshcha shkola, 734 p. [in Ukrainian].
[3] Hryhorov O.V., Okun A.O. (2017). Udoskonalennia matematychnoi modeli rukhu dlia zadachi keruvannia pidiomno-transportnymy mashynamy. [Improvement of the mathematical model of movement for the problem of control of lifting and transport machines]. Avtomobilnyi transport, Kyiv, 127 p. [in Ukrainian].
[4] Kabakov A.M., Telipko L.P. (2024). Matematychne modeliuvannia krana z vantazhem i kerovanymy prystroiamy vibrozakhystu. [Mathematical modeling of a crane with a load and controlled vibration protection devices]. European congress of scientific achievements. Proceedings of the 1st International Scientific and Practical Conference. Barca Academy Publishing, Barcelona, Spain, pp. 91–98. [in Ukrainian].
[5] Ohurtsov A.P. et al. (2002). Diahnostyka, dynamika, nadiinist pidiomno-transportnykh system. [Diagnostics, dynamics, reliability of lifting and transport systems]. Dnipropetrovsk: Systemni tekhnolohii, 368 p. [in Ukrainian].
[6] Doslidzhennia dynamiky, mitsnosti i tekhnolohichnosti mekhanichnykh system. [Research on dynamics, strength, and manufacturability of mechanical systems]. (2017). Monograph. Kamianske: DDTU, 182 p. [in Ukrainian].

УПРАВЛІННЯ ПРИВОДОМ МЕХАНІЗМУ ПІДЙОМУ

Реферат

Вперше розроблено пристрій для управління приводом підйому вантажу, в якому відключення приводу здійснюється не за рівнем динамічних навантажень, а за прогнозованою неприпустимою масою вантажу шляхом вимірювання середньої швидкості розгону механізму на стаціонарній механічній характеристиці приводу. Оскільки швидкість наростання навантаження у канаті при незмінній діючій силі обернено пропорційна масі вантажу, що піднімається, це дозволяє здійснювати управління приводним двигуном на початковій стадії підйому. Це запобігає розвитку значних перевантажень у силових елементах крана.

Література

1. Іванченко Ф.К. Підйомно-транспортні машини. К.: Вища школа. 2008. 413 с.
2. Підйомно-транспортні машини: Розрахунки підіймально-транспортувальних машин / Бондарєв О.І. та ін. К.: Вища школа, 2009, 734 с.
3. Григоров О.В., Окунь А.О. Удосконалення математичної моделі руху. Автомобільний транспорт для задачі керування підйомно-транспортних машин. К. 2017, 127 с.
4. Кабаков А.М., Теліпко Л.П. Математичне моделювання крана з вантажем і керованими пристроями віброзахисту // European congress of scientific achievements. Proceedings of the lst International scientific and practical conference. Barca Academy Publishing. Barcelona, Spain. 2024. pp. 91–98.
5. Огурцов А.П. та інші. Діагностика, динаміка, надійність підйомно-транспортних систем. Дніпропетровськ: Системні технології, 2002, 368 с.
6. Дослідження динаміки, міцності і технологічності механічних систем. Монографія, Кам'янське, ДДТУ, 2017, 182 с.

Надійшла до редколегії 11.11.2025
Прийнята після рецензування 16.01.2026
Опублікована 26.03.2026