Reducing the energy consumption of lifting machines

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Abstract. Modern lifting machines have the ability to recover braking energy and therefore have high energy efficiency. However, the control systems of such machines are of considerable complexity and require the use of storage devices if they work in closed energy supply systems. The paper presents methods for increasing the efficiency of lifting devices at an early stage of design by partial balancing in order to equalize the load during ascent and descent. The technical solutions that can improve the efficiency of modern lifts and shaft elevator systems are presented.

1 Introduction

Energy efficiency is important for design, use and maintenance of lifting machines. The rational use of energy not only reduces the costs of enterprises, but also helps to reduce the impact on the environment. We will study the main aspects that make it possible to achieve high energy efficiency in lifting equipment.

Choosing energy-efficient motors is a key step in improving the efficiency of lifting equipment. The upgraded motors provide a more efficient conversion of electric power into mechanical, which reduces energy consumption and increases productivity.

Energy recovery systems make it possible to use the energy released when braking lifting equipment to recharge batteries or supply additional energy to the electrical network. This reduces the overall level of energy consumption and contributes to more efficient use of resources.

Proper configuration of cargo lifting and lowering systems allows you to optimize the process of energy consumption. For this purpose, intelligent and high-precision control systems are used, which adjust the speed and moment of the load depending on the required operations. Their introduction into production makes it possible to effectively adapt the operation of lifting equipment to the current conditions and needs of the enterprise. The main tasks solved by intelligent control systems are automatic speed control, optimization of movement trajectories and selection of optimal operating modes.

Energy efficiency in lifting equipment is a strategically important task for enterprises. To solve this problem, it requires not only the use of modern technologies and equipment, but also a systematic approach to its use, maintenance and training of personnel. The gradual integration of these activities helps to reduce energy costs and improve the overall efficiency of lifting equipment.

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2 Materials and methods

We will analyze the energy consumption of an unbalanced elevator system without a counterweight with a different amount of cargo carried in the cabin G_c. When lifting a cargo G_c by a winch, as shown in Figure 1, it is required to ensure that the engine power is more significant than the minimum required for steady motion [1,2]

$$N_{max} = - G_c V / \eta \tag{1}$$

where: V is the speed of movement,

η is the efficiency factor.

Almost the same power with the opposite sign will be generated by an engine operating in generator mode when lowering a load of the same magnitude. To recover energy in the cargo descent mode, it is necessary to use a braking energy recovery control system, and in some cases, a storage device for the generated energy. Figure 1 shows the results of modeling the minimum required installed power of the drive motor, depending on the ratio of the weight of the load to the weight of the cabin.

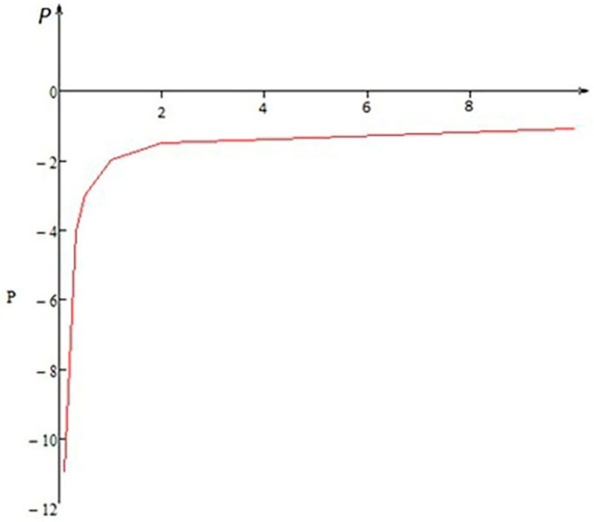

Fig. 1. The calculated dependence of the lifting power costs on the ratio of the weight of the load and the cabin.

In practice, to simplify the drive control system of an unbalanced elevator system, it is often assumed that during descent, excess generated electricity is dissipated on the brake resistors. However, the use of brake resistors entails a number of design inconveniences such as the large dimensions of the brake resistors and their overheating, as well as their mandatory protection from dust and moisture. But, the most unpleasant thing in this case is that excess energy is converted into unnecessary heat, and in some cases it may be necessary to use a cooling system, which will require additional energy costs to maintain.

Therefore, in design practice, in order to reduce the nominal installed power of an electric motor and simplify the control system of the winch drive, they often go to balancing the load of the elevator system with a counterweight, using the equations of static equilibrium of the forces of the load and counterweight [3-5].

Such a traditional balanced elevator system consists of a cabin, a winch and a counterweight (Figure 2b), which is used to balance the weight of a partially loaded cabin. The calculated weight of the $G_{counter}$ counterweight partially balancing the elevator system turns out to be greater than the weight of the empty cabin G_{cab}, but less than the cabin fully loaded with cargo $G_{counter}$ as shown in Figure 2b. [3, 6, 7].

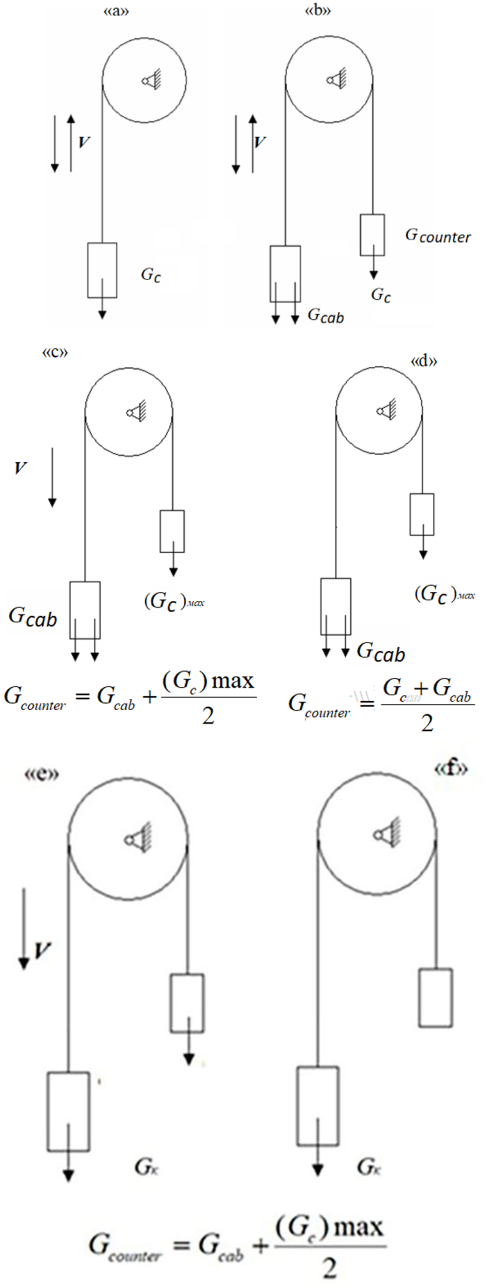

Fig. 2. Various options for the operation of the elevator system: a – work without a balancing counterweight; b – the general case of working with a counterweight; c - descent with maximum load; d – ascent with maximum load; e – descent without load; f - ascent without load.

Thus, balancing is often performed for an average statistical load, for example, choosing the weight of the counterweight $G_{counter}$ to balance the total weight of the cabin G_{cab} and half of the maximum permissible load (G_c)max. In this case, the equation of the static equilibrium of the forces of the load and the counterweight of the elevator system takes the form

$$G_{counter} = G_{cab} + (G_c)_{max} /2 \tag{2}$$

With such a choice of the weight of the counterweight $G_{counter}$, as shown in Figures 2b and 2g, if half of the average statistical calculated load (G_c)max /2 is transported in the cabin, then the engine power is spent only on overcoming the friction forces taken into account by the drive efficiency. I.e., with such a choice of the value of the counterweight and the load equal to half the average calculated value, regardless of the direction of the cabin speed V, the required power of the drive motor is practically close to zero.

We will analyze the energy consumption of an elevator system with a different amount of cargo carried in the cabin G_g, in which the weight of the counterweight is selected according to condition 1 for maximum energy savings with an average statistical load. The maximum engine power is used when a fully loaded cabin is moving up (Figure 1d) or an empty cabin is moving down (Figure 2d and 2e)

$$N_{max} = - (G_{counter})_{max} V /2 \eta \tag{3}$$

When an empty cabin moves up (Figure 2e) or a fully loaded cabin goes down (Figure 2b), the electric motor turns into a generator. The generated power that needs to be recovered is equal to

$$N = (G_c)_{max} V / 2 \eta \tag{4}$$

On the contrary, when an empty cabin goes down (Figure 2e) or a fully loaded cabin goes up (Figure 2b), the electric motor must develop additional power of the same magnitude.

Lifting machines include jacks, winches and hoists. These are working machines designed for lifting and lowering cargo during loading and unloading, construction and repair work.

These mechanisms are often operated manually, have a relatively low load movement speed and lifting height. In most cases, braking energy recovery is ineffective for these devices, especially for jacks designed to lift loads to the required height. However, for individual heavy-duty devices, for example, lifting winches of drilling rigs, energy recovery will reduce the power of the power plant several times without reducing productivity.

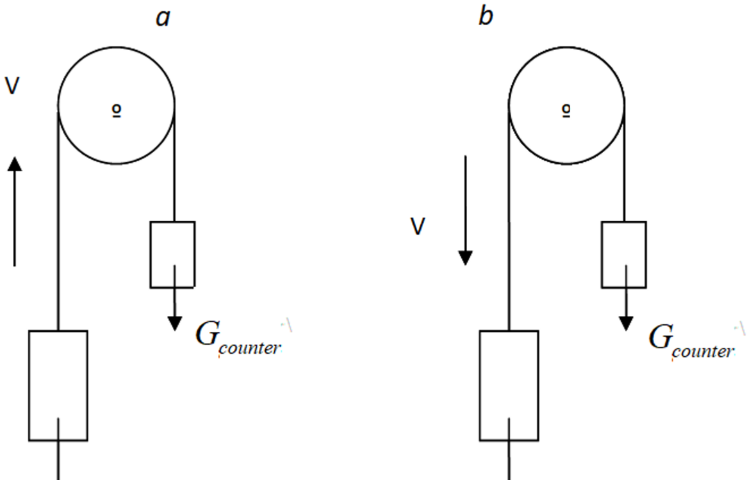

Fig. 3. Movement of the cabin with the load up with minimal energy consumption (a) and down (b).

Lifts are used to move cargo along a given trajectory. The cargo can be on the platform, in a crate or in a cabin. Lifts designed to move people are called elevators. When approaching a stop, the cabin switches to low speed, and the engine runs in generator mode. Electricity is also generated when the loaded cabin is lowered down. Energy recovery is most efficient when there are several elevators operating simultaneously. In this case, a loaded cabin moving downwards can transfer energy to another elevator carrying out the ascent. According to various studies conducted by a number of authors (N.V. Gulia, I.D. Yudovsky, D.A. Kotin, A.K. Afonin), energy savings average about 20%, in some cases reaching 50%. The amount of stored energy primarily depends on the mass of the cargo being lowered and the height of movement. Therefore, in multi-storey office buildings, where there are a large number of continuously operating elevators, energy recovery reaches the highest efficiency.

Lifting cranes are designed to lift and move cargo in space, held by a lifting device [3]. They are the most common lifting machines and have a variety of designs and applications.

Due to the fact that the weight of the cargo moved by the crane can reach 1200 tons, and the lifting height is over 100 meters, energy recovery is quite effective.

The German engineering company Liebherr has developed a hydraulic hybrid drive designed for port cranes. The new Liebherr Pactronic hybrid system is installed on an LHM 550 mobile crane with energy recovery. The system uses additional stored energy, regenerated during the lowering of the load, thanks to which the load rises.

The hydropneumatic system is powered by compressed gas (nitrogen) in conjunction with hydraulic fluid. Due to this, the loading and unloading process is accelerated by 30%. The use of a recuperative system has reduced the cost of the crane, and reduced the amount of harmful emissions into the atmosphere by 30%.

The new hydro-pneumatic system achieves the highest efficiency when operating at maximum capacities. Under normal operating conditions, Liebherr Pactronic provides the crane with fuel savings of up to 30%.

According to representatives of GE Power Conversion, after the application of the recovery system, the energy efficiency of the port crane of the Goliath type increased by 80%.

Software plays an important role in the management of recovery systems. The computer takes into account all external factors affecting the load being moved and regulates the amount of energy supplied to individual crane units. This allows you to reduce the impact loads on the mechanisms, which extends the service life of the structure, and position the load more accurately by adjusting the speed of movement.

In the Russian Federation, studies were conducted on an overhead crane with a flywheel energy accumulator. Studies by a number of authors show that the braking energy loss of one overhead crane with a lifting capacity of 20 tons per shift reaches a value of about 10,000 kJ, which is comparable to the useful energy costs.

3 Results and discussion

Analyzing the process of lifting a loaded cabin (Figure 3a), based on the static equilibrium [9, 10].

$$N_1 = [(G_{cab} + G_c) - G_{counter}] \cdot V \quad (5)$$

for the case of a cabin descent without cargo (Figure 1b)

$$N_2 = (G_{counter} - G_{cab}) \cdot V \quad (6)$$

where V is the cabin speed

G_{cab} is the weight of the cabin,

G_c is the weight of the lifted cargo,

$G_{counter}$ is the weight of the counterweight.

The energy of the lifting electric motor is consumed when the fully loaded cabin moves up (Figure 2g) or the empty cabin moves down (Figure 2d and 2e) [8-10].

It is more convenient to analyze the efficiency of energy consumption to estimate the specific power costs [11, 12] when moving a load at a speed of V, since the value of the drive efficiency may not be taken into account:

$$n_1 = \frac{N_1}{G_c V} = \left(\frac{G_{cab}}{G_c} + \frac{G_{counter}}{G_c} - 1\right) \quad (7)$$

$$n_2 = \frac{N_2}{G_c V} = 1 - \frac{G_{cab}}{G_c} \quad (8)$$

Figure 4 shows the results of calculating the required specific capacities of the lifting electric motor during descent and during ascent, depending on the ratio P_p / P_{pc} at a constant ratio G_c / G_c.

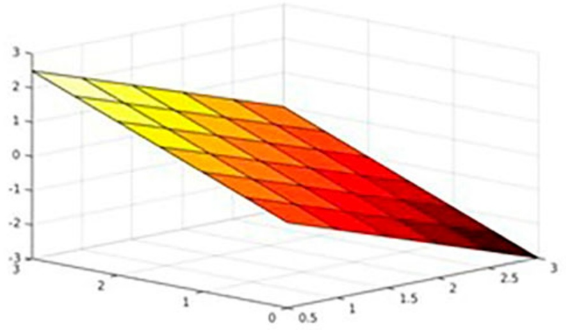

Fig. 4. The dependence of the specific power required on the ratio of the weight of the cabin to the weight of the cargo and the ratio of the weight of the counterweight to the weight of the cargo.

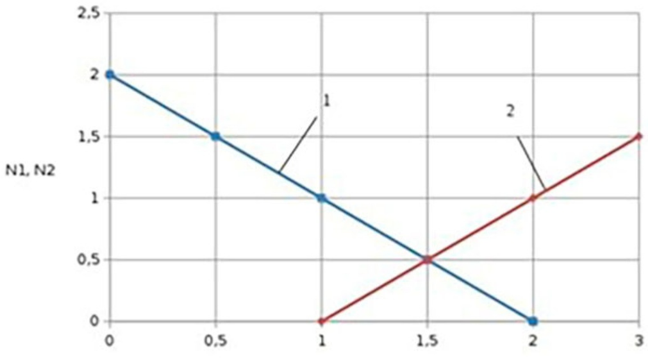

Fig. 5. The calculated dependence of the lifting power costs on the ratio of the weight of the load and the cabin.

Analyzing the calculations of specific capacities during descent and ascent with a constant ratio of the weight of the load to the weight of the cabin, it can be indicated that the required engine power during ascent decreases with increasing weight of the counterweight, and the required power during descent increases under the same conditions.

Note the optimal ratio of the weight of the counterweight and the load being lifted

$$G_{counter}/ G_c = 1.5 \quad (9)$$

during descent and ascent, in which the required capacities per 1 kg of cargo are equal to each other [10].

$$\frac{N1}{V1Gcounter} = \frac{N2}{V2Gcounter} = 0.5 \qquad (10)$$

This "special" point indicates the possibility of using the engine both during descent and ascent with the same power, i.e. to ensure the minimum power of the installed engine, excluding its overload or underloading.

4 Conclusion

The considered designs of lifting machines show that the main dynamic and economic properties of the product are laid down at the initial design stage, and the main criteria are the choice of engine power and counterweight weight. Most of the other calculations have little effect on the dynamic qualities of lifting machines and energy consumption during operation, unless there is a significant increase in moving masses. The main requirements for the implementation of economical operation of lifting machines is the choice of an economic engine and energy recovery system, which is done during the design. This condition is necessary, but insufficient, and its fulfilment provides only a potential opportunity to increase efficiency. To implement this method in practice, it is necessary to combine the economical modes of the engine and the working machine and achieve harmonization of their characteristics by choosing the optimal parameters of the transmission mechanism. An additional increase in the efficiency of lifts and elevator structures can be achieved through the balancing theory. An example of this method is the use of counterweights in an elevator, but the effectiveness of this method decreases when the load being lifted changes during operation. To eliminate this disadvantage, it is necessary to perform automatic balancing in each work cycle.

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