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INNOVATIVE AND ECONOMICALLY FEATURED DESIGN OF CARGO AND PASSENGER PNEUMATIC LIFTS

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Abstract- In this article, the authors consider the problem of transporting goods and passengers in buildings. In Kazakhstan, there are more than 5,000 elevators in operation that have reached their standard service life, according to the National Association of Elevator Engineers of Kazakhstan. A similar situation is observed in the markets of neighboring countries. The authors propose a design for the most promising and effective solution to the problem: cargo and passenger pneumatic lifts. The authors conclude that the proposed design allows for high reliability and safety of operation. Pneumatic lifts are competitive with rope and other types of lifts, and the production of pneumatic lifts allows for a 2-5-fold reduction in manufacturing costs and can be carried out in existing factories without additional equipment.

Keywords: Elevator, Lift, Pneumatic, Pneumatic Elevators, Directing Devices, Dynamics, Dynamic Loads.

1. INTRODUCTION

Currently, there are many types of elevators for lifting cargo and passengers in the world. The most common types include rope and hydraulic elevators. However, the high cost of rope elevators and similar systems, as well as the significant costs of creating a machine room, shafts, and performing finishing, installation, and commissioning work, make them inaccessible to many consumers in countries that do not have their own elevator production. In addition, maintenance of rope, hydraulic, and other types of elevators require the involvement of qualified and well-paid specialists. As a result, this forces such countries to purchase rope, hydraulic, and other types of elevators from foreign manufacturers.

In Kazakhstan, there are more than 5,000 elevators in operation that have exhausted their standard service life (according to the National Association of Elevator Engineers of Kazakhstan). For example, according to Karaganda-Lift LLP, there are 871 elevators in Karaganda, Kazakhstan, 80% of which are subject to complete replacement (have exhausted their resource), and the rest of the service life will expire in the near future.

Due to the lack of spare parts, components and materials, a significant portion of elevators that are still fit for use are idle. A similar situation is observed in other markets in a number of countries without their own elevator manufacturing. The market for light passenger elevators needs to be modernized.

The most promising and effective solution to this problem is the use of innovative equipment - freight and passenger pneumatic elevators [1-2]. The calculations and design developments performed, as well as testing of prototypes of pneumatic elevators, have proven the prospects and possibility of creating such elevators for buildings and structures. At the same time, the simplicity of the design with high reliability and safety of operation allows for a 2-5-fold reduction in the costs of manufacturing, installation and operation of these elevators.

An analysis of the main modern competing technologies of rope, hydraulic and other systems showed that the main advantages of pneumatic lifts compared to rope, hydraulic and other types of elevators are:
- Pneumatic elevators are significantly more affordable in terms of acquisition, installation, and operation costs, being 2 to 5 times less expensive than traditional rope elevators;
- Structural simplicity in manufacture;
- Safety and reliability in operation;
- Operation and installation do not require qualified personnel;
- Low compressed air pressure (0.03-0.07 bar) in the shaft cavity creates favorable and safe dynamic operating conditions for the pneumatic lift.

In addition, when operating a pneumatic lift, unlike other types of elevators, electricity is spent only on lifting cargo or passengers, and lowering the cargo platform or lift cabin occurs without energy consumption under the action of gravity. This determines the energy-efficient operation mode of the pneumatic lift electric drive and leads to energy saving of the lifting equipment as a whole.

A comparison of pneumatic and traditional lifts is presented in Table 1.

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Table 1. Comparison of pneumatic lifts and traditional lifts

Parameter	Pneumatic Lifts	Traditional Lifts (Rope/Hydraulic)
Energy Efficiency	Reduced energy consumption due to the use of compressed air and lack of electric drive for lifting	Higher energy consumption due to the need for an electric drive and other mechanisms
Cost (Acquisition and Installation)	Significantly lower: 2-5 times less expensive compared to rope lifts	High cost due to the need for shaft preparation, machine room, and complex mechanisms
Installation Time	Short, simple construction, does not require significant structural changes	Lengthy, requires shaft preparation and complex mechanism installation
Maintenance	Simple, does not require highly qualified personnel	Labor-intensive, requires regular maintenance by specialists
Safety	High: smooth deceleration due to air cushion in case of emergency	High, but falls may be more dangerous without properly functioning safety systems
Required Air Pressure	0.03-0.07 bar	Not applicable
Need for a Machine Room	Not required	Required
Service Life	Potentially higher with less component wear	Depends on type, may require cable, hydraulic pump replacements, etc.
Environmental Impact	low noise levels	Moderate: requires lubricants, presence of a machine room

2. PNEUMATIC CARGO LIFT OPERATION

The pneumatic cargo lift (Figures 1-8) comprises a shaft 1 made of separate sections of a cylindrical pipe having loading hatches 3 with hinges, eccentric locks 4 and locking devices 5; the inner surface of the hatch 3 is flush with the inner surface of the shaft 1. The loading platform 2 is made in the form of a flat disk 7 installed with a constant annular gap along the inner perimeter of the shaft 1 and containing a ring 6 on which annular elastic elements 8 are fixed, made in the form of separate segments with a floating sealing edge made with tension (tension is the difference between the outer diameter of the ring of the elastic segment 8 and the inner diameter of the shaft 1), fastening elements 9; three vertical posts with rollers at the ends, fixed symmetrically and perpendicular to the plane of the disk 7 at an angle of 120 degrees relative to each other so that all the rollers rest on the inner walls of the shaft 1. Stop devices 10 with limit switches 17 are located at the stop points of the cargo platform at the upper and lower marks of the shaft 1, and retractable stop devices 12 are located on the intermediate sections of the shaft 1 and are extended inside the shaft when it is necessary to stop the cargo platform. In this case, the rods of the retractable stop devices are equipped with limit switches 13 with contacts. The working element is a fan 15, connected by a calibrated branch pipe 16 to the shaft 1. Push-button control posts 18 are designed to start the fan and signal.

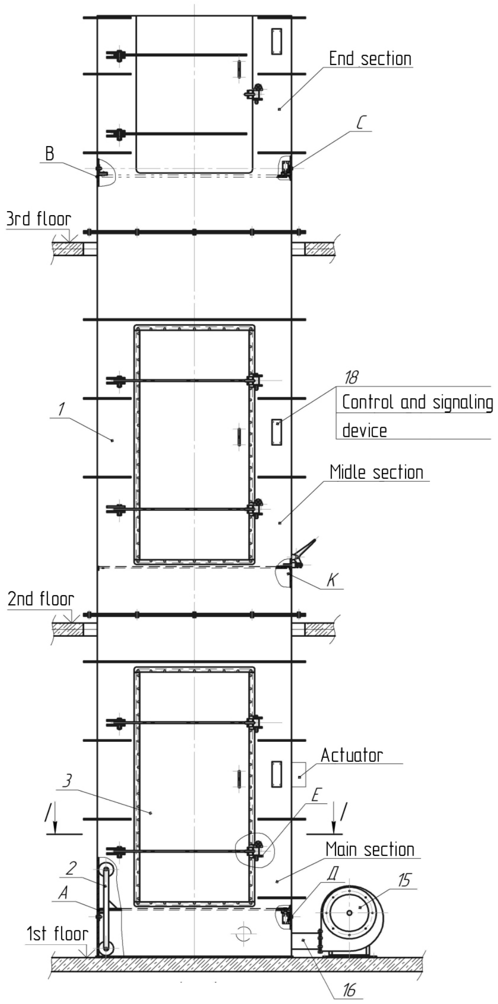

Figure 1. Multi-floor pneumatic elevator

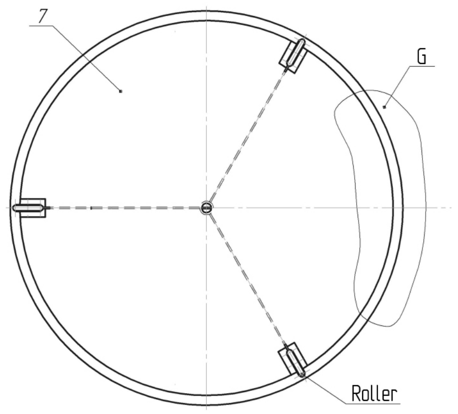

Figure 2. Section 1-1 of a multi-story pneumatic cargo lift

Cargo pneumatic lifts operate as follows: a hatch opens, through which a cargo platform is loaded with various materials, commercial products, etc. The hatch seals the pneumatic lift overpass. The "Start" button is depressed, the working electric drive of the fan is switched on, and air compressed to 0.003-0.005 MPa enters the under-vessel space of the platform.

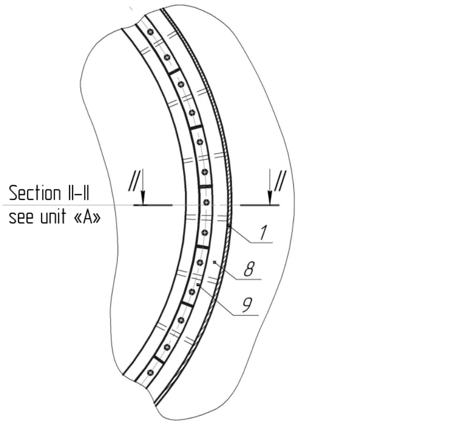

Figure 3. Section II-II and unit "G" of a multi-story pneumatic cargo lift

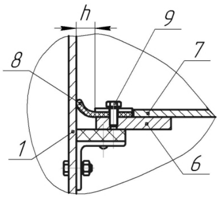

Figure 4. Unit "A" of a multi-story pneumatic cargo lift

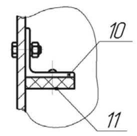

Figure 5. Unit "B" of a multi-story pneumatic cargo lift

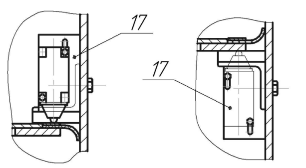

Figure 6. Units' "C" and "D" of a multi-story pneumatic cargo lift

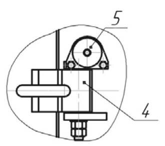

Figure 7. Unit "E" of a multi-story pneumatic cargo lift

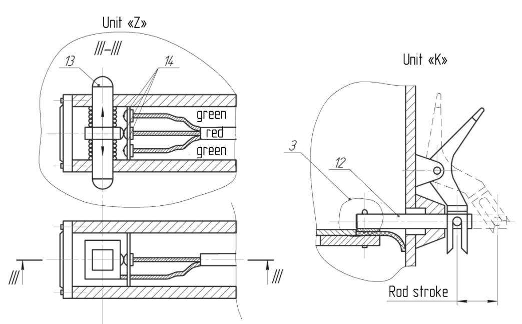

Figure 8. Unit "K", unit "Z" and section III-III of a multi-story pneumatic freight elevator

When a specific calculated pressure is reached, the platform with the load begins to move to the upper edge of the overpass, where it slows down and rests against special dampers. While the platform with the load is located on the upper edge of the overpass, when the platform is loaded or unloaded, it is held by the air pressure coming from the switched-on electric drive of the fan. After loading or unloading the platform with the load, the upper hatch is sealed and the "Stop" button is depressed. The electric drive of the fan is braked, and the air under pressure, which is in the space under the platform with the load, comes out through a specially calibrated opening in the wall of the overpass and begins to throttle, then through the fan structure and goes out into the atmosphere.

At this time, the platform with the load slowly moves down due to compressed air to the lower damper stops, where it finally slows down. The hatch opens and the platform is loaded or unloaded and the operation cycle is repeated.

In order to ensure the safe operation of the pneumatic lift, a hatch blocking device is provided when the cargo platform is in the process of moving (lowering or lifting) along the shaft. The location of the cargo platform is indicated by light signaling fittings (red or green).

If the green light of the signaling fittings is on, then the cargo platform is, respectively, at the lower or upper marks. When the cargo platform is moving in the shaft, the red light of the signaling fittings is on, which warns that the hatch cannot be opened during this period.

If it is necessary to deliver cargo to intermediate floors, the devices 12 are switched on, the rods of which extend into the shaft, the supporting surfaces of which are equipped with limit switches 13 (unit "K"). Limit switches 13 are designed to indicate the location of the cargo platform in the shaft. In all cases of elevator operation, if it touches the limit switch, the green light on the signaling device lights up and it is permitted to open the hatches and carry out unloading (loading) of the platform. When the cargo platform is in an intermediate position, the red light on the signaling device is on and opening the hatches is strictly prohibited. The eccentric hatch locks (unit "E") are equipped with blocking devices that do not allow opening the hatches without permission from the service personnel.

Centering the disk 2 of the cargo platform relative to the shaft axis 1 using vertical posts with rollers ensures a constant gap "h" between the shaft walls and the disk ring 6, which eliminates friction of this ring against the shaft walls, creates favorable operating conditions for the elastic element, ensuring its uniform wear and minimal leaks of compressed air, and the implementation of the elastic element of the ring in the form of separate segments with a floating sealing edge does not require a high degree of cleanliness of the inner surface of the shaft, which significantly reduces the cost of its manufacture. To reduce the coefficient of friction between the walls of the shaft and the sealing edge of the elastic element, the inner surface of the shaft is covered with a material that reduces the coefficient of friction.

The mathematical model of changes in the kinematic, pneumatic and temperature parameters of a pneumatic lifting unit is described by Equations (1):

$$\begin{aligned}
&a=\frac{d^2z}{dt^2}=\frac{1}{M}[(P-P_a)S_c-F_{Pol}-\Sigma F_{Mech}]\\
&\frac{dP}{dt}=\frac{K.R}{S_{Stb}.z}[T_B.\sigma_B-T.\sigma_y-T.\sigma_{Dr}-\\
&-\alpha\frac{K-1}{K.R}(T-T_c).(S_{Dn}+\Pi_c.z)-\frac{P.S_{Stb}.z}{R.dz}]\\
&P_B=A.\sigma_B^2+B.\sigma_B+C\\
&P=P_B-(\lambda_{Tr}\frac{L}{D_{Tr}}+\Sigma\xi_M)\frac{\sigma_B^2.R.T_B}{2P_B-S_{Tr}^2}\\
&\frac{dT}{dt}=\frac{T}{z}.\frac{dz}{dt}+\frac{T}{P}.\frac{dP}{dt}-\frac{R.T^2(\sigma_B-\sigma_y-\sigma_{Dr})}{S_{Stb}.z.P}
\end{aligned} \quad (1)$$

where:
z: current coordinate of skip movement measured from the lower mark of the shaft, m;
a: skip acceleration when moving along the shaft, m/s^2;
t: duration of movement (current time), s;
M: total mass of payload and cabin, kg;
P: current absolute pressure of compressed air in shaft, Pa;
P_a: current value of atmospheric pressure, Pa;
P_B: pressure of compressed air at the fan outlet, Pa;
h: coordinate of the cabin position relative to sea level, m;
P_0: absolute pressure at sea level, Pa;
S_c: cross-sectional area of the cabin, sq.m;
F_{Pol}: useful resistance force, N;
ΣF_{Mech} : total resistance force to cabin movement in the guides and sealing devices of the shaft, N;
K_T: cabin tare coefficient;
K: heat capacity coefficient equal to ratio of heat capacity at constant pressure to heat capacity at constant volume;
S_{Tr}: area of the cabin bottom, m^2;
α: heat transfer coefficient;
σ_B: blower weight capacity, kg/s;
σ_y: air weight flow rate during leaks, kg/s;
σ_{Dr}: air weight flow rate during throttling, kg/s;
T: temperature in the subvessel cavity, K;
A, B, C: constant coefficients according to the fan operating characteristic;
R: universal gas constant, J/(mol K);
T_B: air temperature supplied from the fan, K;
P_B: air pressure supplied from the fan, Pa;
λ_{Mr}: hydraulic coefficient of shaft friction;
Π_c: cabin perimeter, m;
ξ_M : local resistance coefficient;
D_{Mr}: shaft diameter, m;
L: shaft length, m;
H: cabin height, m.

3. PNEUMATIC PASSENGER LIFT OPERATION

Structurally, a pneumatic lift consists of a shaft located in a building, guide and sealing devices, a lift cabin (or a lifting vessel for cargo), a working element (fan) and control devices (Figure 9).

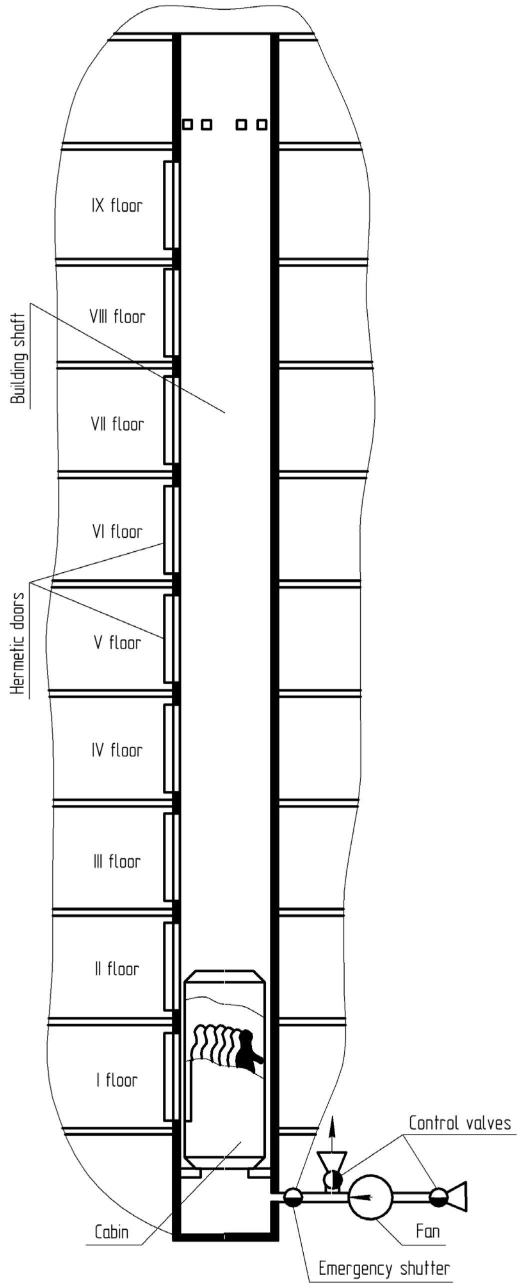

Figure 9. Schematic diagram of a passenger pneumatic lift

The pneumatic lift operates as follows: after a person enters the cabin or the lifting vessel is loaded with cargo, a signal is sent to turn on the working element, as a result of which compressed air begins to flow under the bottom of the cabin (vessel), and after reaching a certain pressure (0.03-0.07 bar), the latter begins to rise to a given mark in the shaft, moving along guide rollers. The cabin (vessel) is sealed (to prevent air leaks) with special elastic elements fixed to the walls of the shaft.

The cabin is lowered to the lower mark of the shaft due to its own gravity, after part of the compressed air from the under-vessel cavity of the shaft is released into the atmosphere. All pneumatic lift control operations are performed using devices located in the cabin and on the inlet pipeline.

The need to develop and industrialize pneumatic lifts in Kazakhstan is dictated by the following reasons [4-5]:
1. The urgent need to equip newly constructed buildings and structures with lifting equipment for transporting goods and people;
2. The depreciation of the existing fleet of elevator installations and the need to replace them;
3. The high cost of cable and other elevator installations, their components and spare parts manufactured abroad;
4. The lack of production of elevator installations for freight and human use in Kazakhstan and hence the strict dependence on foreign suppliers of elevator equipment;
5. A significant market.

Based on market demand, there is a need to create pneumatic lifts of the following modifications:
1. Human pneumatic lifts with a lifting capacity of 6 people (480 kg) for 9-12-story buildings;
2. Freight (for bulk and piece goods);
3. Small freight (up to 110 kg) for canteens, restaurants, shops, etc.;
4. Human for high-rise buildings (30-60 floors) with a lifting capacity of 30-40 people (2400-3200 kg).

From the above-listed modifications of elevators, cargo pneumatic lifts PPG-100, PPG-250 and PPG-500 were created, with a lifting capacity of 110, 250 and 500 kg (Figure 10), the tests of which have proven the operability and reliability of these machines [2].

Figure 10. Pneumatic lifts with a lifting capacity of 110, 250, 500 Kg [2]

Figure 11 shows some test results that establish the dependence of changing pressure in the working cavity of the loaded platform on the lifting time of PPG-110, 250, 500.

Figure 12 shows the parameters of the current consumption of a three-phase electric motor with voltage of 380 V when lifting the PPG-110, PPG-250 and PPG-500 loaded platforms.

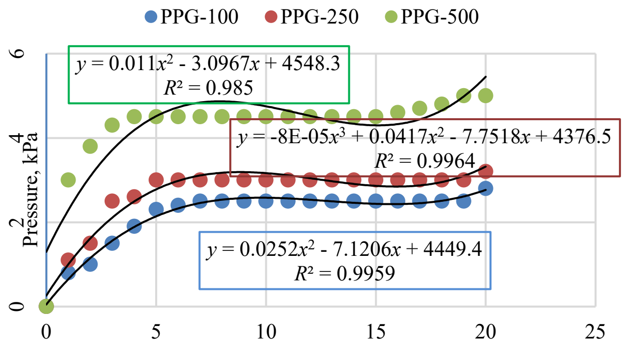

Figure 11. The working cavity of the loaded platform pressure dependence on the lifting time [15]

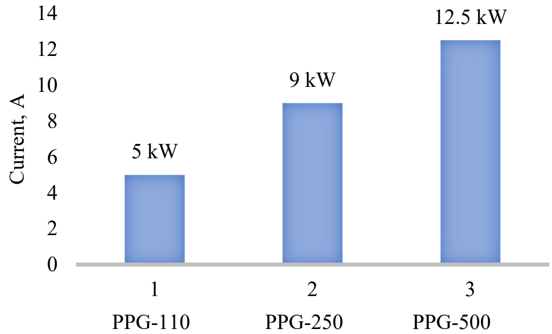

Figure 12. Experimental data on the operating current when lifting the PPG-110, 250, 500 loading platforms [15]

The air consumption values for lifting the PPG-110, PPG-250 and PPG-500 load platforms of pneumatic hoists have been obtained experimentally.

The following equipment and devices have been used to measure the parameters: a pressure gauge of the NMP-52UZ type with the measurement limit of 0-5 kPa; a dynamometer; the power and electrical energy consumption has been measured using an ARRA-30R electrical measuring clamp with a flexible system for measuring operating voltage and current; the time has been measured using a chronometer; the load during testing of the pneumatic load hoist has been provided by reference weights.

Table 2. Air consumption when lifting a low-speed cargo platform of pneumatic lifts [2]

Lifting capacity, kg	Speed of movement when lifting, m/s	The area of the shaft, m^2	Air flow, m^3/s
110	0.178	0.785	0.137
250	0.18	1.54	0.28
500	0.193	2	0.386

According to the measurements of the electrical parameters, the pneumatic load hoists shows the following indicators: the consumption of electrical energy when lifting an empty platform is 7 Wh, and 13 Wh per lift when lifting a loaded platform. When taking a motor of the same power for a rope hoist for comparison, it will consume at least 1.5 times more energy per "lifting - lowering" cycle, since the PPG-100 hoist under consideration does not consume electrical energy when descending.

The platform is lowered by removing air from the under-vessel cavity naturally. The power of the motor with a fan is 2.7 kW when lifting an empty platform, and 2.85 kW when lifting a loaded platform, which allows concluding that even when lifting the maximum load, there is a power reserve.

We recommend using the specified pneumatic lifts when designing new facilities and reconstructing stores, canteens, restaurants, warehouses, etc. Pneumatic lifts are manufactured in Karaganda, are simple in design and do not require the arrangement of a shaft.

Technical and economic assessment and comparison of parameters of rope and pneumatic lifts for a 9-story building showed that the use of pneumatic lifts reduces capital investments by 4.6 thousand US dollars per set with the same costs for installation and adjustment work. It follows that in addition to technical advantages, pneumatic lifts also provide an economic effect. The cost of a pneumatic lift in serial production will be 8.5 thousand US dollars.

4. CONCLUSIONS

One of the key advantages of this type of elevator is the safety of its operation, which is built into its design. In case of emergency situations (for example, power outage or electric motor failure), the cargo platform or elevator cabin does not fall down, but stops first, after which it begins to descend slowly due to air throttling, creating an air cushion underneath. Even a shaft depressurization does not pose a danger to passengers, since after checking this section, the cabin will also smoothly slow down. At the same time, the higher the shaft, the safer the structure as a whole, since only the lowest part of the shaft (less than the cabin braking distance) poses a danger, having strengthened which, the issue of accidents when elevators fall is resolved.

Environmental conditions during operation of pneumatic lifts impose restrictions only on the operation of rubber sealing devices. In freight and passenger pneumatic lifts, sealing devices made of rubber mixture HO-68-1 HTA are used, which is intended for the manufacture of oil- and petrol-resistant rubber parts operating in air, oils, petrol and grease in the temperature range from -55 to +100 °C. Thus, freight and passenger pneumatic lifts can be operated even in the harshest conditions at ambient temperatures from -55 to +100 °C.

Due to this, all the necessary conditions are in place (affordable price of the machine and its maintenance costs, safety and reliability in operation, no transport and customs costs, and no need for highly qualified service personnel) for the implementation of pneumatic cargo lifts at enterprises in Kazakhstan and other countries. This, in turn, makes it possible to reduce the dependence of Kazakhstan on foreign suppliers of such equipment, provide reliable service and repair of machines, and solve the issue of lifting cargo in the long term.

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