Mobile robotic air cushion system

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Abstract. Currently, a variety of mobile robotic platforms are widely used. One of its areas of application is the transportation of heavy loads. In addition, such systems can be used in the development of the Arctic as auxiliary tools for the construction and maintenance of research bases and equipment warehouses on them. Also, the use of mobile robotic platforms will increase the efficiency of mineral development in the Arctic shelf zone and, in the future, automate this process to a greater or lesser extent. At the same time, classic mobile robotic platforms have a number of serious disadvantages that are associated with their design. The main problem is the high degree of wear on the rollers and the relatively rapid destruction of the main structural elements due to the resulting transverse forces. These forces occur due to errors when installing the rollers. But they can be significantly reduced by equipping the mobile platform with an air cushion. This article defines the importance of using an air cushion in the design of mobile robotic platforms. A schematic diagram of a classic hovercraft is described. The existing schemes for creating an air cushion skirt are presented, their main characteristic features are noted, and advantages and disadvantages are indicated. The layout of a mobile robotic platform on an air cushion is presented. A dependence is obtained that shows the effectiveness of using an air cushion for this layout. The analysis of its movement parameters is made, the dependences between the required power of the supercharger and the weight of the transported cargo are investigated, depending on the size of the gap between the seal and the floor.

1. Introduction
Currently, mobile robotic systems are widely used. For example, they are used to transport heavy equipment and various cargoes. Such systems can be used in the development of the Arctic as auxiliary tools for the construction and maintenance of research bases and equipment warehouses on them [1], [2]. In addition, using mobile robotic systems can not only improve the efficiency of mining in the Arctic shelf zone, but also in the future to automate it to some extent [3].

Analysis of existing solutions has shown that the main problem of their operation is high wear of the rollers and destruction of the main structural elements. The greatest influence is exerted by the transverse forces that arise due to errors in the installation of the rollers, in consequence of which there are transverse sliding friction forces.

These forces can be significantly reduced (by 50-90%) using air cushion technology. In this case, you can create the necessary friction forces between the support surface and the rollers by adjusting the power of the air cushion.
2. Air cushion vehicle
The traditional hovercraft [4] has been known since the 18th century, when a British engineer, John Isaac Thornycroft, obtained a patent for a hovercraft. However, the first such devices appeared only in the XX century.

2.1. General concept
A classic hovercraft (figure 1) consists of a platform, the lower part of which is equipped with a flexible skirt (4). Special superchargers (3), driven by the power plant, pump air (2) into the cavity formed by the bottom of the platform and the skirt. The excess pressure created in this way raises the vehicle, which is actually hovering above the ground. An additional fan (1) is used for moving.

![Figure 1. Schematic diagram of a hovercraft](image)

Currently, several types of skirts are used, each of which has its own limitations or requirements for the surface or design.

2.2. Balloon skirt
The main requirement when using this type of skirt (figure 2) – the shape of the vehicle must be round or close to it. In other forms, the air injection system does not work properly. There is also a limit on the height of the skirt – no more than 10-15% of the diameter of the vehicle. Otherwise, it may lose stability.

![Figure 2. Balloon skirt](image)

Since there are air losses through the gap between the floor and the skirt (which is true for any type of skirt), it is necessary to take them into account when determining the parameters of the supercharger. At the same time, the lower the surface roughness, the less these losses are.

2.3. Peripheral jet skirt
This type of skirt is formed by a jet or stream of air moving at high speed. The best option is when the air flow from the supercharger is directed inward at an angle of 45° (figure 3). In this case, it is possible to reach the maximum lifting height. The disadvantage of this type of skirt is low energy efficiency.
2.4. Skirt with an annular nozzle around the perimeter of the pillow and its variants
This form of skirt (figure 4, a) allows for high stability of the air cushion [5]. Another advantage of this skirt is that it can be used on vehicles of any shape. In this case, there is no need to design a channel through which air would follow from the supercharger to the seal, since in this case it is fed directly into the cavity under the bottom and into the annular cylinder located along the perimeter. Depending on the type of surface, the amount of pressure in the cylinder changes – it can be equal to the pressure in the chamber or be higher than it (in this case, it is more difficult to move on rough surfaces).

A further development of the skirt with an annular nozzle is the "finger" skirt (figure 4, b). This skirt consists of separate sections that are installed side by side and have the ability to move relative to each other. Thanks to this, this skirt can almost perfectly repeat the shape of the floor. Despite the higher complexity in the manufacture of such a skirt, it is quite common, because it allows you to achieve lower friction indicators, and this design is more convenient from the point of view of repair, since it is enough to replace only the damaged section of the skirt.

3. Mobile robotic air cushion system
The main problem that arises when developing mobile robotic systems designed for the transport of heavy loads is obvious. The more weight it carries, the more load-carrying the rollers must be and the more precisely the drive system elements must be manufactured and mounted. In addition, powerful drives are required to move large loads. All this leads to an increase in the cost of the system.
To reduce the cost of a mobile robotic system, it is necessary to reduce the weight carried with it. This can be achieved by using an air cushion, compensating for the weight of the load by the excess pressure created under the bottom of the platform. The design of such a robotic system is shown in figure 5.
Figure 5. Mobile robotic system for cargo transportation, equipped with an air cushion

Table 1 shows the values of the main characteristics of the mobile robotic system.

Table 1. Main characteristics of the mobile robotic system

| Characteristic                  | Value       |
|--------------------------------|-------------|
| Platform weight, kg            | 800         |
| Payload, kg                    | 500…10000   |
| Platform dimensions (LxWxH), m | 2x1x0,1     |
| Travel speed, m/s              | 0,3 м/с     |

4. Motion study
During the study of the movement process of the mobile robotic system, the magnitude of the emerging forces of resistance to movement was estimated [6]. Then a relationship was obtained that reflects the relationship between the payload and the engine power required to move the mobile robotic system with and without an air cushion (figure 6). In the first case, 70% of the payload on the platform was compensated with an air cushion.
As can be seen from the obtained dependence, when using an air cushion, the engine power required to move the system is 40% lower than when the air cushion is not used (for a load of 4000 kg).

To determine the parameters of the supercharger that creates excess pressure in the air cushion, you must determine the required air flow. To do this, you need to estimate the losses that occur due to friction in the seal. This can be done using the Bernoulli equation [7, 8]:

$$p + \rho g z + \frac{\rho}{2} c^2 = \text{const.}$$  \hspace{1cm} (1)

Although this equation is only valid for incompressible flows, and air is a compressible medium, it can also be used here. This assumption is due to the fact that the density of air varies in such a small range that it can actually be considered incompressible.

The losses to be determined are due to friction. To find them, add the corresponding value ($\Delta p$) to the Bernoulli equation (1):

$$p_1 + \rho g z_1 + \frac{\rho}{2} c_1^2 = p_2 + \rho g z_2 + \frac{\rho}{2} c_2^2 + \Delta p$$  \hspace{1cm} (2)

The amount of losses is determined by empirical coefficients $\xi_R$ and $\xi_E$ [9, 10]. The first takes into account the loss of friction in the walls of the channel through which the air moves, and the second—the loss arising from the disruption of the flow on the internal surfaces. Then the amount of loss will take the form:

$$\Delta p = \xi_R \frac{\rho}{2} c^2 + 2 \xi_E \frac{\rho}{2} c^2$$  \hspace{1cm} (3)

After composing expressions for the coefficients $\xi_R$ and $\xi_E$, we get:

$$\Delta p = \frac{0.316}{s^4 \cdot 2s} \cdot \frac{L \rho}{v} c^2 + 2 \xi_E \frac{\rho}{2} c^2$$  \hspace{1cm} (4)

Solving the obtained equation, we determined the dependence of the volume flow rate of the superchargers and the required power on the weight of the payload for different gaps (h) between the seal and the floor surface (figure 7, a and b).
5. Conclusion

The results of the study show that the use of an air cushion in mobile robotic systems is appropriate, since it reduces the power required to move the load. Was obtained dependence, reflecting the link between energy efficiency, air cushion and the size of the payload for different gaps $h$ (figure 8, a), and between efficiency and the size of the gap $h$ for different masses of the payload (figure 8, b).

In figure 8, and the positive area of each curve corresponds to the case when the use of an air cushion is justified from the point of view of energy efficiency. However, in some cases, there may be a situation when the use of this technology is not an optimal solution. Thus, for a gap of 0.25 mm, the critical mass is 3500 kg, after which the required engine power when using an air cushion system exceeds the power for a similar system without it. If the gap is reduced, the efficiency of the air cushion system increases significantly.

Using the graph shown in figure 8, b, it is possible to determine the optimal values of the gap $h$ for a certain payload mass—they correspond to the positive region of each of the constructed curves. If, for some reason, the optimal gap $h$ cannot be reached in the actual design, it is necessary to increase the dimensions of the transport cart in order to maintain the energy efficiency of the system.
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