Justification of parameters of the executive drive of a robotic manipulator of a loading and transport unit

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Abstract. To solve the problem of mechanization and automation of loading operations when harvesting vegetables Packed in bags, a loading and transport unit is proposed. A parallel-sequential structure manipulator has been developed for the loading and transport robot. The service area of the pincer grip is obtained from the condition of the specified chassis width. The geometrical parameters of the manipulator boom actuating drive from the condition of providing the required service area are justified. The choice of actuators is based on the condition of minimizing the influence of the maximum value of the force acting on the output link. The analytical dependence of the force on the rod of the Executive actuator on the angle of inclination of the arm of the manipulator is obtained. Graphical dependences of the force on the actuator rod on the angle of rotation of the boom in the form of a three-dimensional surface are constructed. Analytically favorable conditions for the transfer of motion and forces in mechanics are formulated. The quality of motion transmission in the lever mechanisms of the manipulator was evaluated according to the criteria for reducing the pressure angles in the hinges. The description of the loading and transport robot manipulator device is presented. An experimental sample of a parallel-serial manipulator was developed and manufactured. Taking into account the formulated dependencies and limitations allowed us to create a universal prototype of the manipulator, which can be installed on various self-propelled chassis. A system for controlling actuators according to various laws of program movements has been developed. Determining the coordinates of bags of vegetables is determined by the technical vision system.

1. Introduction

In agro-industrial production, a large volume of piece cargo consists of bags, boxes, soft bags and nets with vegetable products Packed in them weighing from 20 to 80 kg. For example, harvesting onions, carrots, and sometimes potatoes is most often done by packing them in nets directly on the field, then loading them on vehicles and delivering them to the place of sale. In the technological process of harvesting, this is one of the most labor-intensive operations [1, 2, 3].

2. Materials and methods

To solve the problems of mechanization and automation of loading and transport operations when collecting nets with vegetables directly from the field, the design of the manipulator of the loading and transport robotic unit was developed. The proposed robot loader allows you to load nets with vegetables in the field into the body and transport them to the place of unloading. The wheel chassis of the VTZ-30SSH is used as the base (Figure 1)
For the developed manipulator, first of all, the degree of mobility of gripping nets with vegetables is justified. The gripper of the loading manipulator has the ability to move relative to the body of the self-propelled chassis in three coordinates $x, y, z$ in order to position the grid over the body area, and also has additional mobility that orients it in space. To ensure maneuverability in the base plane the number of generalized coordinates of the manipulator exceeds the number of orienting coordinates of the capture [4, 5, 6, 7].

![Figure 1. Working area of the loading robot gripper with a parallel – sequential structure manipulator](image)

The main task of designing the boom swing drive is to determine the rational places for the attachment points of the slave cylinders that provide the required coverage area (boom swing angle) and the minimum dimensions of the drive mechanism, taking into account the maximum rod stroke [8, 9].

3. Justification of parameters
To justify the parameters of the Executive cylinders of the boom drive of the parallelogram mechanism, consider the design scheme (Figure 2), taking the following symbols $AB=r$ - the radius of the crank; $AO=h$ - the center distance; $OB=l$ - the current length of the Executive cylinder. Moreover, $\theta$ - is the value of a variable and varies within $l_{min} \leq l \leq l_{max}$.

![Figure 2. to determine the rational parameters of the boom actuator](image)
To determine the geometric parameters $h$ and $r$, it is necessary to solve the problem of finding solutions taking into account the typical range of stroke of the electric cylinder rod (0.4; 0.63; etc.). Based on the cosine theorem and given that the angle $\phi$ belongs to the range $0,5 \leq \phi \leq 2.7$ and is given from the condition of providing the required service area, we obtain the expression

$$
\begin{align*}
I_{\text{min}}^2 &= r^2 + h^2 - 2 \cdot h \cdot r \cdot \cos(\pi - \phi_{\text{max}}) \\
I_{\text{max}}^2 &= r^2 + h^2 - 2 \cdot h \cdot r \cdot \cos(\pi - \phi_{\text{min}})
\end{align*}
$$

Using the vector contour projection equations $\vec{h} + \vec{r} = \vec{l}$ on the coordinate axis and trigonometric dependencies, after a series of transformations, we obtain expressions for determining the parameters $r$ (2) and $h$ (3)

$$
\begin{align*}
h &= \frac{\sqrt{c_1 + c_2} + \sqrt{c_2 - c_1}}{2} \\
r &= \frac{\sqrt{c_1 + c_2} - \sqrt{c_2 - c_1}}{2}
\end{align*}
$$

where $c_1 = \frac{I_{\text{max}}^2 - I_{\text{min}}^2}{\cos \alpha_{\text{min}} - \cos \alpha_{\text{max}}}$, $c_2 = \frac{I_{\text{max}}^2 \cdot \cos \alpha_{\text{min}} - I_{\text{min}}^2 \cdot \cos \alpha_{\text{max}}}{\cos \alpha_{\text{min}} - \cos \alpha_{\text{max}}}$.

$l_{\text{max}}$ and $l_{\text{min}}$ – maximum and minimum extension of the Executive cylinder.

Using the obtained dependencies (2) and (3), partially given some initial parameters, it is possible to choose rational points of the cylinder attachment depending on its elongation. For example, for the above values of the maximum and minimum elongation of the slave cylinder for a given maximum angle of rotation of $90^0$, $r = 159.4 \text{ mm}$ and $h = 505.6 \text{ mm}$ are obtained.

On the other hand, when synthesizing the geometric parameters of the loading manipulator mechanism, a criterion for minimizing the loads on the actuator drives is required.

Minimization of the maximum value of the force $P_{\text{max}}$ developed by the drive at various positions of the output link provides a reduction in the cost of the drive, which is usually a significant part of the cost of the manipulator [9].

From the equation of the moments of forces relative to point $A$ (Figure 2), taking into account the force reduced to the levers of the rotary parallelogram mechanism, the dependence of the force on the rod of the electric cylinder on the angle of rotation $P(\phi)$

$$
P(\phi) = \frac{mgL \cdot \sin(\frac{\pi}{2} - \phi)}{r \cdot \sin(\phi - \phi_1)} \rightarrow \text{min}.
$$

Expression (4) can serve as a test for the maximum developed force by the electric cylinder, or the values of $r$ and $h$ can be adjusted when $P(\phi)$ is minimized. So, for example, according to the obtained dependence (4) for $r = 159.4 \text{ mm}$, the change in the force on the rod of the electric cylinder with a reduced bag weight of 30 kg will be from -1586 N to 4135 N with the angle ranges $\phi=45...1200$ (Figure3). The resulting solutions make it possible to use two SKF electric cylinders connected in parallel with a developed force of 2300 N.
Figure 3. Dependence of the force on the electric cylinder rod on the angle of rotation $\varphi$ and the crank radius $r$

The efficiency of the designed linkage mechanisms is assessed according to the quality criteria of the transmission of motion and forces. To assess the transmission quality, the definition of the generalized quality criterion for the transmission of motion $K$ for our case (Figure 4)

$$K = \frac{P_{\text{mov}} \cdot r}{M} = \frac{1}{\cos \beta}$$

Where $\beta$ - is the pressure angle in the joint $B$

Figure 4. determining the criteria for the quality of force transfer and movement

A favorable condition for the transfer of movement and forces in the mechanism will be when

$$K \leq [K]$$

where $[K] = 1, 5...3, 0$ - is the maximum allowed values of the criterion.

Since the criterion $K$ depends on the pressure angle, we determine the intervals of its change

$$\beta = \frac{\pi}{2} - \gamma, \text{ by } \gamma > \frac{\pi}{2}$$
$$\beta = 0, \text{ by } \gamma = 0$$
$$\beta = \gamma - \frac{\pi}{2}, \text{ by } \gamma < \frac{\pi}{2}$$

(6)
As the calculations show, \( K \leq 2 \), i.e. does not exceed the limit values.

Taking into account certain parameters, the manipulator structure is assembled (Figure 5), which consists of a frame 1 mounted on the spars of a self-propelled wheel chassis, a replacement body 2. The frame is pivotally attached to the rocker 3 of the parallelogram mechanism, on the other side of which the platform 4 is pivotally installed. The rocker 3 and platform 4 are the main bearing boom of the manipulator. Electric cylinders 5 are attached to the platform 4, the ends of which are connected in a universal joint 6. Electric Cylinders 4 are installed in such a way that they are a mechanism of a parallel structure in the form of a tripod. Finally, the universal joint 6 is attached to a controlled clamp 7 for meshes with vegetables 8.

![Figure 5. Appearance of the parallel-sequential structure manipulator for the loading and transport robot](image)

### 4. Conclusion
The developed manipulator of a parallel-serial structure can be installed on the «Agromash» SSH-50 or VZT-30SSH self-propelled chassis. The resulting working area of the gripping of the manipulator of the robotic loader provides full coverage of the entire body area along the chassis width.

To control the manipulator actuators, a control system has been developed that allows implementing the specified program laws of motion. The manipulator is equipped with a technical vision system for recognizing the coordinates of vegetable grids relative to the coordinate system connected directly to the chassis body [9, 10].

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