Investigation and analysis of the linear dimensions of the flexible manipulator section in the process of tilting

Konstantin Semenov¹, Andrey Medyakov¹, Petr Fischenko¹, and Denis Lastochkin¹

¹ Volga State University of Technology, 424000 Yoshkar-Ola, Russia

Abstract. A feature of the functioning of such a device is a change in the position of each of the sections. The study of the peculiarities of changing the position of the link is an important task. The article investigates the features of the functioning of the flexible manipulator link in the process of tilting. Three rods are responsible for the process of changing the position of the link. Depending on the nature of the movement rods increase or decrease in length. The principle of position changing when the link is tilted evenly on two rods is considered. With the help of analytical geometry the analysis of changes in the linear dimensions of moving elements is carried out. The results of the calculations are presented in the form of graphs and allow us to show the process of changing the position of the rods in the process of tilting.

1 Introduction

Interest in manipulators based on flexible joints is associated with the possibility of their use in those conditions where articulated manipulators are not able to perform operations. The advantage of flexible manipulators is a large working area in comparison with articulated ones, as well as a large degree of freedom. [1,2]

In areas of activity where the execution of technological operations is carried out in limited spaces, manipulators on flexible joints are introduced.

There are various principles in the design of flexible manipulators. [3,4] A feature of the design of the known manipulators on flexible joints is the low rigidity of the structure which reduces the weight of the perceived loads.

Also as a working body of a manipulator it is proposed to use a flexible manipulator [5,6]. To describe the principles of functioning of the manipulator it is necessary to describe the change in the position of the body during the tilt.[6,7]

The purpose of the study. This paper describes the kinematics of a flexible manipulator for determining the operating conditions of the link drive rod during the tilt process.
2 Materials and methods

Methods of analytical geometry, as well as methods of numerical solution of systems of nonlinear equations were used in the research [8]

3 Research results

To analyze the geometric characteristics of flexible manipulators with flexible connections, we will analyze the manipulator [9]. The tilt scheme of the link is shown in Fig. 1.

![Fig. 1. The tilt scheme of the flexible manipulator link](image)

As can be seen from Figure 1 the manipulator consists of two bases to the center of which the axes are attached. The movement of the bases is achieved by connecting the two axes using a hinge mechanism. The adjustment of the tilt position of the link is carried out by three rods installed at an equal distance along the perimeter of the bases. The angle \( \theta \) is accepted as the characteristic of the link tilt. In this scheme the tilt is carried out evenly on the rods and \( M_{K1}M'_{K1}M_{K2}M'_{K2} \).

To determine the change in the linear dimensions of the rods in the process of tilting the link a diagram of the tilt on the rod is constructed \( C_1 \), Fig. 2. The investigated parameter in this case will be the angle of inclination \( \alpha \) and the length of the rod \( C_1 \).

![Fig. 2. Diagram of geometric parameters when tilted towards one rod](image)
The investigated parameter in this case will be the angle of inclination $\alpha$ and the length of the rod $C_1$. The sides $r$, $l$ and the angle of inclination of the link $\theta$ are taken as initial parameters.

According to Figure 2 we have:

$$c_1 = d \sqrt{2(1 - \cos\gamma_1)}$$  \hspace{2cm} (1)

where

$$d = \sqrt{l^2 + r^2}$$  \hspace{2cm} (2)

$$\gamma = \pi - \theta - 2\phi$$  \hspace{2cm} (3)

Substituting (2), (3) into (1) we get

$$c_1 = \sqrt{2(l^2 + r^2)(1 - \cos(\pi - \theta - 2\phi))}$$  \hspace{2cm} (4)

$\phi$ can be found by the formula:

$$\phi = \arctan \frac{r}{l}$$

Substituting this expression into formula (4) we have:

$$c_1 = \sqrt{2(l^2 + r^2)(1 - \cos(\pi - \theta - 2\arctan \frac{r}{l}))}$$  \hspace{2cm} (5)

A necessary condition for determining the features of functioning of the manipulator link is the angle $\alpha$, which characterizes the tilt.

Similarly to the calculation principle of formula (3), we obtain the following expression:

$$\alpha = \pi - \left(\frac{\pi}{2} + \gamma_1\right) - \lambda$$  \hspace{2cm} (6)

where

$$\lambda = \arccos \frac{c_1}{2d}$$  \hspace{2cm} (7)

Substituting the expression (4), (5) and (7) into formula (6), we obtain

$$\alpha = \pi - \left(\frac{\pi}{2} + (\pi - \theta - 2\arctan \frac{r}{l})\right) - \arccos \sqrt{\frac{2(l^2 + r^2)(1 - \cos(\pi - \theta - 2\arctan \frac{r}{l}))}{2d}}$$

After simplification, the formula takes the following form:

$$\alpha = -\frac{\pi}{2} + \theta + 2\arctan \frac{r}{l} - \arccos \sqrt{(1 - \cos(\pi - \theta - 2\arctan \frac{r}{l}))}$$  \hspace{2cm} (8)

To determine the change in the linear dimensions of the rods during the tilt of the link, a diagram of the tilt towards one rod is constructed $C_2$, Fig. 3. The investigated parameter in this case will be the angle of inclination of the length of the rod $C_2$. 
The investigated parameter according to Figure 3 is the length of the rod \( C_2 \). The sides \( r, l \) and the angle of inclination of the link \( \theta \) are taken as initial parameters in the same way as Figure 2.

\[
c_2 = d\sqrt{2(1 - \cos \gamma_2)}
\]

where

\[
\gamma_2 = \pi - 2\varphi + \theta
\]

Substituting (2) and the value of \( \varphi \) into the formula (9) we have:

\[
c_2 = \sqrt{l^2 + r^2} \cdot \sqrt{2(1 - \cos(\pi - 2\arctan \frac{r}{l} + \theta))}
\]

Thus, equations describing the change in distances \( c_1 \) and \( c_2 \) and angle \( \alpha \) during the link tilt of the flexible manipulator are obtained.

The values \( l=1; \ r=1, \ \theta \in (0^\circ; 20^\circ) \) were taken as input parameters. The maximum angle of inclination of 20° was chosen on the basis of studies presented in the source [10]. The calculation results are presented in the table 1.

Table 1. As a result of calculations the following values are obtained:

<table>
<thead>
<tr>
<th>( \theta )</th>
<th>( c_1 )</th>
<th>( c_2 )</th>
<th>( \alpha, \text{ grad.} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>( \frac{\pi}{36} ) (5 deg.)</td>
<td>1.950315</td>
<td>2.04848</td>
<td>80.01463</td>
</tr>
<tr>
<td>( \frac{\pi}{18} ) (10 deg.)</td>
<td>1.910858</td>
<td>2.085335</td>
<td>77.82918</td>
</tr>
<tr>
<td>( \frac{\pi}{12} ) (15 deg.)</td>
<td>1.818078</td>
<td>2.166701</td>
<td>75.37288</td>
</tr>
<tr>
<td>( \frac{\pi}{9} ) (20 deg.)</td>
<td>1.721837</td>
<td>2.243942</td>
<td>74.41989</td>
</tr>
</tbody>
</table>
The graphs of the length change of the rods are characterized by a linear dependence (Figure 4-5). When changing the main parameters related to the dimensions of the link $r$, $l$, formulas (5) and (11) are applicable to determine the change in the lengths of the rods $c_1$ and $c_2$. In such case the graph will also have a linear form.

Taking into account the fact that the size $r=l$ length $c_1$ changes by 0.86 from the original, and the length $c_2$ changes by 1.122 from the original.

To analyze the functioning of the manipulator link it is necessary to determine how the inclination of the rods changes during the link tilt. To do this, a graph $\theta(\alpha)$ is constructed.

The graph in the figure shows the fact that at small inclination angles of the link $\theta$ there is a sharp change in the inclination angle of the rod $\alpha$. When increasing the tilt by more than 5 deg. not a significant change in the angle $\alpha$ is characteristic. In the future, this feature of the rods must be taken into account during the operation of the manipulator. Including in the development of elements for fixing rods to the bases of the manipulator link.

4 Conclusion

Thus, based on the results of calculations it is necessary to take into account the dimensions of the main elements that make up the link. When developing a model of the flexible manipulator operation it is necessary to take into account the changes in the linear dimensions
of the rods and the principles of operation of the drive mechanisms. It is necessary to take into account the following statements that have been received:

1. When the link of the flexible manipulator is tilted from the vertical position (0 degrees) to 20 degrees there is a change in the inclination angle of the rod, the angle graph resembles a hyperbola;
2. With a small inclination of the link (up to 5 degrees) a significant change in the inclination angle of the rods is observed;
3. When the link is tilted more than 5 degrees there is a slight change in the inclination angle of the rod.

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References