Modelling and Simulation Research of the Gripper Manipulator

Dawid Cekus, Dorian Skrobek
Instytut Mechaniki i Podstaw Konstrukcji Maszyn, Politechnika Częstochowska
e-mail: cekus@imipkm.pcz.pl, skrobek@imipkm.pcz.pl

Abstract

The paper introduces issues related to the design of the gripper manipulator. The displacement, velocity and force characteristics of the gripper manipulator have been determined. The drives of the grippers have been selected, and static analyses with the help of finite method (in SolidWorks program) have been conducted. The simulation models of the gripper manipulators in Matlab/Simulink environment have been carried out.

Keywords: gripper manipulator, design, modeling, simulation, FEM, Matlab/Simulink

1. Introduction

Manipulator is a system of arm connected by joints and a gripping device ended. These elements are widely discussed in the literature [Bicchi and Kumar 2000, Cutkosky 1985, Eizicovits and Berman 2014]. The working out of the gripper of a manipulator that carries shaft/sleeve having a circular cross-section has been the aim of the paper. Jaw of manipulator has been designed to hoist and hold the load during the duty cycle.

2. Kinematics of the gripper

For the project purposes it was assumed that the mass of the lifted load is equal 1 kg and the range of diameters of the shaft/sleeve is equal 160-180 mm. In the paper the two diagrams of the jaws manipulator (Fig. 1) have been considered and for them the kinematics has been solved. On the basis of kinematic schemes the jaws mobility has been determined and for both schemes is equal 1. It means that to drive of the gripper one electric actuator with linear movement will be applied. The kinematic diagram of the gripper in two positions (Fig. 1) has been examined for the determination of minimum and maximum diameter of the gripped element.

As the maximum cylinder stroke was adopted 50 mm ($S=x_{max}-x_{min}$). Other preliminary dimensions of the members have been denoted in kinematic schemes and they have following values: $L_1=62.5$ mm, $L_2=140$ mm, $L_3=150$ mm, $L_4=180$ mm, $L_5=40$ mm (for scheme 1 - Fig. 1a); $L_1=140$ mm, $L_2=150$ mm,
On the basis of accepted criteria the range of jaws opening of the gripper ($\Delta y = 2(y_{\text{max}} - y_{\text{min}})$) and maximum dimensions of gripped object (shaft/sleeve) have been determined [Felis et al 2004].

In the present case we are dealing with the force way of grasping an object. This method involves the applying of appropriate force (normal to the surface of the jaw) on a transported object. The friction force between the jaw and the shaft/sleeve ensures the transfer of element. To define the gripping force the determination of the friction and normal force is needful, as indicated in Fig. 2.

For proper grasp of the transported object the condition must be fulfilled:

$$F_{ch} = 2 \cdot N \cdot \cos(90^\circ - \gamma)$$

where: $\gamma$ - the angle of flare of the gripper jaws, $\mu$ - the coefficient of friction between the gripper jaws and the object.

For proper grasp of the transported object the condition must be fulfilled:
where: $Q$ - the weight of the transported object, $n$ - overload factor of the gripper.

Hence, the grip force and the maximum grip force:

$$ F_{ch} \geq \frac{Q \cdot n \cdot \sin(\gamma)}{2 \cdot \mu}, \quad F_{ch_{max}} \geq \frac{Q_{max} \cdot n \cdot \sin(\gamma)}{2 \cdot \mu}. \quad (5,6) $$

To properly grasp of the object the determination of the minimal dimension of the jaw is demanded:

$$ \tan(\gamma) = \frac{d}{2 \cdot e_{min}}, \text{ hence: } e_{min} = \frac{d}{2 \cdot \tan(\gamma)} \text{ and: } e_{min} = \frac{d}{2 \cdot \tan(\gamma)}. \quad (7,8,9) $$

To determine the characteristics of the displacements of the gripper defining the relationship between the opening jaws and the linear displacement of the electric actuator the analytical method has been applied. For solution of the problem the coordinate system OXY (Fig. 3) was adopted.

![Fig. 3. Schemes of jaws to determine the displacement characteristics](image)

In the kinematic scheme the closed vector polygon has been inscribed and the angles that create with the axes of the coordinate system have been denoted. On the basis of schemes presented in Fig. 3a and 3b the following relationships can be written:

$$\begin{align*}
x + L_2 \cdot \cos(\phi) - L_4 &= 0, \\
L_1 + L_2 \cdot \sin(\phi) - y &= 0, \\
x - L_1 \cdot \cos(\phi) - x_1 &= 0, \\
y - L_1 \cdot \sin(\phi) - y_1 &= 0.
\end{align*}\quad (10,11)$$

Finally the displacements characteristics (Fig. 4) of the gripper for both schemes is determined by the following formulae:
\[ y = L_1 + \sqrt{L_2^2 - (L_4 - x)^2}, \quad y_1 = y_1 + \sqrt{L_1^2 - (x - x_1)^2}. \] (12,13)

The angle of rotation of the third member can be written as follows:

\[ \tan(\phi) = \frac{y - L_1}{L_4 - x} = \frac{\sqrt{L_2^2 - (L_4 - x)^2}}{L_4 - x}, \quad \tan(\phi) = \frac{y - y_1}{x - x_1} = \frac{\sqrt{L_1^2 - (x - x_1)^2}}{x - x_1}. \] (14,15)

The velocity characteristics of the gripper is determined analogically using the analytical method. In practice, it comes down to write the derivative with respect of time of the displacements characteristics:

\[ \dot{y} = \frac{L_4 - x}{\sqrt{L_2^2 - (L_4 - x)^2}} \cdot \dot{x}, \quad \dot{y}_1 = -\frac{x - x_1}{\sqrt{L_1^2 - (x - x_1)^2}} \cdot \dot{x}. \] (16,17)

Ultimately the velocity characteristics can be defined:

\[ f_v(x) = \frac{\dot{y}}{x} = \frac{L_4 - x}{\sqrt{L_2^2 - (L_4 - x)^2}}, \quad f_v(x) = \frac{\dot{y}_1}{x} = -\frac{x - x_1}{\sqrt{L_1^2 - (x - x_1)^2}}, \] (18,19)

where: \( \dot{x} \) - the velocity of the piston rod, \( \dot{y} \) - the velocity of the working tip.

![Diagram](attachment:diagram.png)

Fig. 4. The displacement characteristics of grippers. The velocity characteristics of grippers

The velocity characteristics (Fig. 4) can be also determined using the method of the velocity plans. This method consists of writing the vector equations defining the velocity of characteristic points of the mechanism.

Determination of the force characteristics of the gripper consists in determining the ratio of gripping force to the force on the piston rod of the actuator as a function of displacement. This characteristic enables specify the maximum force on the actuator required to achieve maximum gripping force. It is the basis of the selection of the actuator. The force characteristic allows also to define the scope
of the actuator stroke. The analyzed case is limited to static analysis in which the
gravity force, the force of inertia and the friction force in the kinematic pairs have
been omitted. Due to the symmetry of the mechanism the structural group 3-4
(Fig. 5) has been examined. The forces in the group 3'-4' are the same. After the
determination of the structural forces, the force analyses of moving link for both
schemes have been determined:

\[ F_s = 2 \cdot R_A \cdot \cos(\varphi) = 2 \cdot \frac{F_{ch}}{\sin(\varphi)} \cdot \cos(\varphi) = 2 \cdot F_{ch} \cdot \cot(\varphi). \]  
(20)

![Fig. 5. The computational model of the gripper to determine the force characteristics (a),
the force analysis in the structural group (b).](image)

\[ f_F(x) = \frac{F_{ch}}{F_s} = \frac{F_{ch}}{2 \cdot F_{ch} \cdot \cot(\varphi)} = \frac{1}{2} \cdot \cot(\varphi) = \frac{\sqrt{L_2^2 - (L_4 - x)^2}}{2 \cdot (L_4 - x)}, \]  
(21)

![Fig. 6. The force characteristics of the gripper](image)
3. Project in CAD system

On the basis of adopted schemes of grippers (Fig. 1), two models of the grippers have been designed in SolidWorks program (Fig. 7). For both models the static analyses have been conducted. In the computational models: at the joints of the jaw with the forearm all degrees of freedom were removed, the friction between the elements has been given, screw and pin joints have been taken account, the models loaded by force actuator (20) and grip force (5) with the revised mark for stabilization of the model. The geometrical dimensions of the model are the same as those adopted in section 2 of this paper.

\[
f_F(x) = \frac{F_{ch}}{F_s} = \frac{F_{ch}}{2 \cdot F_{ch} \cdot \cotg(\varphi)} = \frac{1}{2 \cdot \cotg(\varphi)} = \frac{\sqrt{L_x^2 - (x - x_1)^2}}{2 \cdot (x - x_1)}
\]  (22)

In Fig. 8-10 the results of static analysis for both models are illustrated. In both models, the biggest resultant displacement occur at the ends of the jaws. The displacements are smaller than 1 mm. This shows that the components of the jaws will not to bend under the influence of gripping force (forces acting on the jaw). Such displacement indicates the reliable grip of transferred element. In the present case, the positioning accuracy will depend only on the precision work of manipulator. In the case of stress distribution according to Huber-Mises hypothesis the yield strength of the material have not been exceeded (in both models).

Fig. 7. Models of the grippers

Fig. 8. Stress distributions according to Huber-Mises hypothesis in the grippers
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Fig. 8. Stress distributions according to Huber-Mises hypothesis in the grippers

Fig. 9. Equivalent deformations in the grippers

Fig. 10. Displacements in the grippers

4. Simulation model

The simulation models have been created on the basis of implementation CAD model into the Matlab/Simulink environment [Cekus et al. 2014]. The SimMechanics model, obtained immediately after implementation, includes a block scheme and allows only visualizing mechanism (Fig. 11), without possibility of carrying out simulation research. Simulation tests may be conducted only after some modifications (like removing unnecessary constraints between elements of the model or changing their types) and the addition of the control signals (kinematic excitations – Fig. 13) and actuators to the model. The final block scheme for the chosen gripper (Fig. 11a) is shown in Figure 12. In this scheme, some elements were combined into subsystems [Cekus 2012, Cekus et al. 2014]. The block scheme for the second gripper looks very similar therefore it was not included in this paper.

Fig. 11. Visualization of the gripper models in Matlab/Simulink (with marked local coordinate systems and centers of gravity)
On the basis of kinematic excitations (Fig. 13) (identical course for both grippers) the results illustrating the relationship between the actuator displacement and displacement of left and right jaws have been obtained and presented in Fig. 14.

Fig. 12. The SimMechanic scheme of the gripper

Fig. 13. Control signals for both models of the grippers

5. Conclusions

In the paper one of the design methodology of the gripper manipulator has been presented.
The increase of the stroke on the actuator by 1 mm causes the displacement of jaws in model 1 (Fig. 11a) equal 0.716 mm, while in model 2 (Fig. 11b) equal 0.9036 mm.

Relationship between the velocity of motion of the actuator (in accordance with a control signal) and the velocity of motion of the jaws (left and right) for the models is shown in Fig. 15.

5. Conclusions

In the paper one of the design methodology of the gripper manipulator has been presented.
The proposed of kinematic schemes was the first step of design. On the basis of the kinematic schemes the displacement, velocity and force characteristics have been determined. It allowed the selection of the appropriate drives of grippers. Then the parametric geometrical models in SolidWorks have been carried out and the static analyses have been conducted. The construction of simulation models in Matlab/Simulink environment was the last step of study.

Based on the carried out study it can be concluded that the designed jaws can be used in the light industry, where the reliable grip is important as well as the transferred elements have the circular cross section and small weight.

Furthermore the proposed jaws will be used in the manipulator mounted on the Mars rover build at the Technical University of Czestochowa.

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References

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