Research and Design of Fast and Light Bearing Gripper Manipulator Summary

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Abstract. This article is based on the situation that domestic and foreign bearing manufacturers still need a lot of labor costs to complete the finished bearing grabbing and recycling after bearing assembly. A fast and lightweight finished bearing grab robot is developed and designed, and it has a lightweight and flexible robotic mechanism. Based on the physical characteristics and objective indicators of the grasping object, carries out lightweight structural design of the manipulator and completes the modular design of important joints, parts, and connection components.

Keywords: manipulator; modular design; three-dimensional modeling; lightweight structural design; motion simulation.

1. Foreword
Aiming at the phenomenon of manual pickup of finished bearings that are still widely used in bearing production lines, this article has designed a fast and lightweight finished bearing gripping manipulator. This paper mainly made a detailed design plan for the overall design of the manipulator [1], based on the object grabbed by the manipulator is a precision part with lighter weight and higher precision requirements-bearing. Through the realization of lightweight structural design [2], it completes the specific structural design of modular joints, joint connectors, arm external bracket construction, etc., and carries out model analysis of key parts of the manipulator. By constructing constitutive mathematical equations, and system optimization using the results of motion simulation research.

2. Robot configuration
2.1. Manipulator grab requirements
The main purpose of using the manipulator to complete the finished bearing grasping process is to achieve the purpose of reducing manual labor in the process and realize automatic grasping and recycling [3]. The manipulator is required to be able to position and grab, and complete the task of transferring the finished bearing to the specified position quickly and accurately. Therefore, the basic requirements for the manipulator are as follows:

There is no interference in the movement stroke of the manipulator, coordinate with the linear running speed of the line bearing to ensure the "one-catch-one-movement" movement cycle.

The positioning detection of the manipulator has sufficient accuracy.
Manipulator load capacity: $\geq 40$N. The gripping force of the manipulator can be set by the pressurizing device of the hydraulic system, and the minimum must not be less than 40N.

2.2. Freedom analysis and action design

To analyze the actual bearing grasping work requirements, the manipulator needs to reach two positions in the same plane or different planes in a movement cycle.

The analysis of the movement requirements shows that the robot. Up and down need at least 1 degree of freedom control, and rotation requires at least one degree of freedom of rotation. Control and analysis shows that the above-mentioned motion manipulator requires at least 2 degrees of freedom to complete [4].

2.3. Overall structure design

Through the analysis of the structural scheme, according to the requirements of use, the overall appearance structure model diagram of the mechanical arm is designed as follows:

The detailed design parameters of the manipulator are as follows:

- Bearing size: the outer ring diameter is about 30~45mm, the bearing is flat cylindrical and the material is steel.
- Rotation angle of support: 180°, maximum rotation speed is 25°/s.
- Y-axis boom length: 18cm, maximum rotation angle around X-axis is 120°
- Y-axis arm length: 15.8cm, maximum rotation angle around X-axis is 175°

Robot design guidelines:

(1) Structural lightweighting criteria

At present, the design criteria of a large number of industrial robots in terms of structural weight are basically: the mechanical structure accounts for more than 70% of the overall structure weight, the threaded connection accounts for 20% of the overall structure weight, and 10% structural redundancy is left. The lightweight design of industrial robots or manipulators has considerable practical significance for the flexible positioning of the manipulator and the energy consumption of the hydraulic drive movement [5].

In the light-weight design of the structure, the mechanical performance of the structure should be focused on, and the mechanical performance of the parts should be matched, and it is easy to install and maintain, and the part structure is reasonably optimized under the premise of using functions [6].

(2) Use safety guidelines

The safety of use is including structural safety, hydraulic sealing safety and human-machine interaction safety. Structural safety needs to ensure that the mechanical structure has reliable dynamic and static stability; hydraulic sealing safety needs to ensure that the hydraulic transmission system is well sealed and there are no hidden safety hazards; human-computer interaction security is reflected in the interaction process of the user operating the mechanical arm, it cannot cause harm to the surrounding environment or human body.

The following is a detailed analysis of the key parts of the robot arm:

3. Hand Design

As shown in the configuration diagram of the manipulator shown in Figure 2, the design adopts the most typical two-finger inner clamping in the clamping hand structure, the advantage is that a diamond-like screw plate is added at the base of the finger.

It can be seen from the figure that the distance from the pivot point of the finger to the center of symmetry is a, the finger length is b, the clamping force is FN, and the driving force is FP. When the bearing is clamped, the angle between the direction of the finger chute and the two pivot points is $\alpha$. Available formula as follows:
The combined range of $\alpha$ is $20^\circ \sim 45^\circ$.
The clamping force of the robot on the workpiece is calculated according to the following formula:

$$F_N = \frac{kG\sin \alpha}{2\mu}$$  \hspace{1cm} (2)

In the formula, $k$ is the safety factor, taking 1.5~3.0; $G$ is the gravity of the bearing; $\alpha$ is the angle between the direction of the finger chute and the two pivot points when the bearing is clamped; $\mu$ is the coefficient of friction between the bearing and the grip.

Set $a=106$, $b=232$, $\alpha=30^\circ$, find the clamping force $F_N$ and driving force $F_p$.

Let the safety factor be $k=1.5$, $G=mg$, $\mu=0.3$.

Substituting the known conditions, the clamping force can be obtained as:

$$F_N = 23.1N$$

The driving force is:

$$F_p = \frac{2b\cos^2 \alpha}{a} = 32.1N$$

Note: In practical applications, mechanical efficiency needs to be considered, take $\eta=0.85~0.95$ Take $\eta=0.9$, Available $F_s=F_p\eta=28.9N$.

4. Design of wrist, arm and upright

As shown in Figure 3, the configuration of the wrist and column of the robotic arm. The total length of the wrist and arm is 268.31mm, and the total length of the column is 189.88mm.

4.1. Wrist design

The wrist structure designed in this project is a wrist structure with one degree of freedom. The resistance to be overcome is mainly the rotational inertia of the wrist, so the effort should be kept stable. The transmission mechanism is intended to use hydraulic transmission.

Calculation of the driving torque of the wrist:

There are three kinds of resistance to be overcome when the wrist rotates:

1. Friction torque in the chute when the wrist rotates $M_f$

$$M_f = 0.1M$$  \hspace{1cm} (3)

$M$: total torque

2. Overcome the bias torque of the center of gravity of the bearing $M_p$

$$M_p = Ge$$  \hspace{1cm} (4)

$G$: bearing weight

e: vertical distance from the center of gravity of the bearing to the axis of rotation of the wrist

3. Torque required to overcome starting inertia $M_g$

$$M_g = (J + J_z)\frac{\omega}{2\varphi_c}$$  \hspace{1cm} (5)

Note: $J$: Rotational inertia of hand rotation to wrist rotation axis

$J_z$: The moment of inertia of the bearing to the axis of rotation of the wrist

$\omega$: Wrist rotation angular velocity

$\varphi_c$: Angle of rotation during startup

So $M = M_f + M_p + M_g$  \hspace{1cm} (6)

By substituting the physical parameters of the clamping bearing into the given formula.
4.2. Arm design
The robot arm designed in the crank rocker mechanism is adopted, and the transmission mechanism is a hydraulic transmission.

(1) The stroke length L of the arm rocker is determined
Determine the horizontal length of the rocker according to the design requirements. In order to prevent the rocker from colliding with the hydraulic cylinder wall, there is a margin for its travel. Consult the itinerary manual to know: L=150mm

(2) Rocker stability calculation
When the length of the rocker L≥10m (m is the thickness of the rocker), When the wrist is subjected to excessive load in the vertical direction, the rocker is bent and deformed, resulting in instability, which prevents the rocker from being accurately positioned.

Stable conditions:

\[ F_{c} \leq \frac{F_{m}}{n_{m}} \]  

\( n_{m} \): rocker stability safety factor, take \( n_{m}=3~7 \)
Because the clamping object is a high-precision light-weight bearing, it can be checked by force.

4.3. Column design
According to the design requirements, the length of the column is 189mm.

Institutional design calculation:
Inertia moment M inertia calculation:

\[ M_{g} = J_{0} = J_{0} + \frac{\Delta \omega}{\Delta \epsilon} \]

\[ J_{0} = J_{r} + \frac{g \beta^{2}}{g} \]

\[ J_{r} = \frac{m (L_{r})^{2}}{12} \]

4.4. Base design
Due to the characteristics of facing the gripping object, the lower part of the design base uses a suction cup fixing method to replace the traditional ground bolt connection, which is convenient for disassembly, stable grip, and good interpersonal harmony.

Note: The center distance between two adjacent flanges of the base is 80mm, and the flange radius is 12mm

Fourth, complete the assembly of the three-dimensional model of the Manipulator.

Assemble the above components to obtain a three-dimensional model of the manipulator, as shown in Figure 4.

![Figure 1. Robot](image1)
![Figure 2. Configuration diagram](image2)
![Figure 3. Robotic arm](image3)
![Figure 4. Manipulator](image4)
5. Manipulator motion parameter analysis and key parameter optimization

5.1. Positive kinematics research of manipulator

This topic intends to use a typical robot positive kinematics analysis method-DH parameter method. The relationship between the joint coordinate systems can be obtained as follows. The general formula for homogeneous transformation between adjacent joints shown:

\[ T_{i}^{-1} T_{i-1} = \begin{pmatrix}
    c\theta_{i} & -s\theta_{i} & 0 & a_{i-1} \\
    s\theta_{i}c\alpha_{i-1} & c\theta_{i}c\alpha_{i-1} & -s\alpha_{i-1} & -d_{i}s\alpha_{i-1} \\
    0 & s\theta_{i} & c\theta_{i} & 0 \\
    0 & 0 & 0 & 1
\end{pmatrix} \]  

Note: c: cos; s: sin

Bringing the data in the nominal D-H parameter table into the above equations can be obtained \( T_{1} \), \( T_{2} \), \( T_{3} \), \( T_{4} \) separately, and the relationship between the palm and the base \( T_{0} \) can be obtained through the homogeneous transformation matrix. After determining the joint angle of each joint \( \theta_{i} \) and bringing it into the matrix \( T_{0} \), the spatial position of the terminal finger in the base space coordinate system can be obtained.

Based on the results of the positive kinematics matrix of the above-mentioned manipulator, the average calculation is performed within the range of motion of each movable joint, and the working space of the manipulator is formed by countless movements up to the space point. The working space is shown in Figure 7.

5.2. Manipulator kinematics simulation

This program is to verify the correctness of the manipulator's positive kinematics solution, use Matlab programming software to write the program, and use Robotic Toolbox to combine the manipulator's motion space calculation results to perform motion simulation and plan the motion trajectory for the key joint angle.

Through the kinematic analytic expression of equation (11), the movement trajectory of the palm of the robot arm in its working space is obtained, and the position and posture of the manipulator obtained by the positive kinematics are substituted into the expression to solve each. The three joints are in a good coupling state corresponding to the motion angles at the same time. There is no motion interference in the establishment of the theoretical model. The design feasibility is initially determined, and the kinematics of the robot can be determined.

6. Manipulator motion simulation analysis

6.1. Simulation principle

According to the motion characteristics of the manipulator, the corresponding geometric constraint driving model is established in the Solidworks software, and the simplified three-dimensional model of the manipulator is established according to the actual size of the motion mechanism, and the actual connection between the connecting rod and the connecting rod is simplified into a hinge connection to complete the rotary auxiliary device. Set up the corresponding driving model for the link drive, and import the simplified model into Adams for dynamic simulation.
6.2. Simplified manipulator model
As shown in Figure 5, it is a simplified schematic diagram of the overall three-dimensional model of the manipulator. The basis for simplification is as follows:

1. Treat all parts of the robot as a rigid body;
2. Some detailed features that have little effect on the simulation results, such as chamfering and fine holes, screws, conveyor belts, etc.; to facilitate the better analysis of the movement characteristics of the entire structure. Check the simplified assembly model. The inspection contents include: assembly model interference, density information of the mechanism, quality attributes, etc. The simplified structure is shown below.

6.3. Set the motion pair of the joint
Import the robotic arm model as shown in Figure 6 and prepare to start the motion simulation. First fix the base of the robot arm to the ground, so create a fixed pair (JOINT_1) between the base of the robot arm and the ground (ground), as shown in Figure 6.

After that, the joint motion pairs of the overall movement of the manipulator are established. According to the actual motion situation, the six joints of the manipulator are rotating pairs, so the rotating joints are added to the remaining joints. The final model effect picture is shown in Figure 7.

6.4. Add joint drive
Set the top six joint rotation angular speeds from top to bottom to 150, 160, 170, 340, 340, 520 °/s, the acceleration time of each joint is 1s. The speed function of each joint is as follows:

\[
\text{step}(\text{time},0,0,8,150d);\text{step}(\text{time},0,0,8,160d);\text{step}(\text{time},0,0,8,170d);\text{step}(\text{time},0,0,8,340d)
\]
\[
\text{step}(\text{time},0,0,8,340d);\text{step}(\text{time},0,0,8,520d)
\]

As shown in Figure 8, it is the added joint drive effect diagram.

Figure 5. Simplified manipulator model

Figure 6. Robotic arm model

Figure 7. Final model

Figure 8. Added joint drive effect diagram
6.5. Dynamics simulation
The displacement, velocity, and acceleration of the end of the manipulator are simulated respectively, and the joint motion parameter maps shown in Figures 9, 10, and 11 are obtained.

![Figure 9. The joint motion parameter maps](image)

![Figure 10. The joint motion parameter maps](image)

![Figure 11. The joint motion parameter maps](image)

It can be found from the figure that the maximum displacement, speed and acceleration of the end of the robot arm are 1.0m, 10m/s and 175m/s², respectively. In addition, it can also be seen from the figure that at 0.5s, there is an inflection point in the three figures. This is because the driving force of the terminal motor changes direction during the movement, and the ADAMS simulation force results are positive, so there is a turning point.

7. Conclusion
(1) Completed the structural design of the quick and light bearing gripping manipulator.
(2) Completed the manipulator motion parameter analysis and key parameter optimization, and analyzed the related simulation data through Matlab, used Adams to simulate the manipulator motion, thus proving its stability and lightweight structure.
(3) The positive kinematics solution is completed by the established kinematics model of the manipulator, and the results of the positive kinematics solution are verified by the Matlab software.

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