Simulation and Analysis of a Kind of Cam Manipulator Based on Rigid Flexible Coupling Dynamics Theory

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Abstract. Based on the theory of rigid flexible coupling, a cam manipulator used in an automatic production line is simulated. By comparing the differences between rigid body system and rigid flexible coupling system in various dynamic performance indexes, it can be seen that the positioning accuracy and stability of manipulator movement are affected by the elasticity of components. In the case of high accuracy requirements, the elasticity of members cannot be ignored. The simulation analysis provides the basis for the following optimization design and machining.

1. Introduction
In the industrial automation production, a large number of manipulators are used to complete various action requirements. There are many ways to realize the structure of the manipulator. The cam is a very good choice in the application of simple action and low precision requirements.

The cam mechanism has not only high reliability but also simple structure. This paper is aimed at the assembly manipulator of a specific position in an automatic assembly machine of electronic products, as shown in Figure 1. Based on the rigid flexible coupling, the dynamic analysis of the manipulator is carried out to determine its performance at work.

Figure 1. Cam manipulator in automatic assembly machinery
2. Design of manipulator cam
The manipulator needs to realize the function of picking up parts and placing them in the designated position. According to the action requirements in the plane, it can be divided into two directions, vertical and horizontal. The specific driven rules in each direction are shown in Figure 2 and figure 3.

![Figure 2. Vertical displacement of manipulator](image)

![Figure 3. Horizontal displacement of manipulator](image)

The design of manipulator cam can be based on SolidWorks software. Based on the motion module of the software, a linear motor is added in the vertical and horizontal directions of the manipulator, and the motion law is set according to Fig. 2 and Fig. 3. The theoretical contour lines of the two cams can be obtained by tracking the tracks of the roller centers of the two cam followers respectively, as shown in Figure 4. Further considering the influence of roller radius, the actual contour can be obtained, and finally the cam model can be obtained.

![Figure 4. Theoretical contour of cam](image)

![Figure 5. Final design result of cam](image)

3. Dynamic analysis of cam

3.1. Principle of rigid flexible coupling analysis
The common dynamic simulation analysis uses rigid components, which is an ideal situation, that is, there is no deformation under the action of force. In reality, most of the components can be treated as rigid body to ensure that the error is within the acceptable range, because the elastic deformation between the parts has little impact on the dynamic characteristics of each part of the mechanism.

When the accuracy is very high or the component structure is relatively weak, the deformation of the component will affect the overall accuracy to a certain extent, select the appropriate component as the flexible body analysis, so the calculation results will be relatively accurate. The connection and stress relationship between components must be considered when adding rigid flexible coupling system constraints, which is more likely to restore the actual working conditions, so that the model is more realistic.
The flexible body is composed of modes. To get the flexible body, it is necessary to calculate the modes of the components. Mode is a physical property of component itself. The geometric model of the component is discretized by the finite element technology to obtain the mesh model. The sum of all the node degrees of freedom of the model constitutes the degree of freedom of the finite element model. How many degrees of freedom a finite element model has, how many modes it has. The actual displacement of each node of the component is the linear superposition of the modes in a certain proportion.

#### 3.2. Analysis pretreatment

The 3D model designed by SolidWorks is imported into Adams, and then constraints are added according to the actual situation. In order to reduce the computing resources, necessary simplification is needed. The main matching is as follows: the camshaft and the frame are set as hinge pairs, the two cams and shafts are set as locking, the cam roller and the swing rod are set as locking, the straight guide rod and the movable support are set as cylinder pairs. Finally, two pairs of cams and rollers are set as solid contact, as shown in Fig. 6.

Due to the large deformation of slender members in the process of movement, four guide rods are selected to be converted into flexible bodies, and the material is set as steel. After calculation, the mode of the rod can be obtained, and the deformation is obvious as shown in Fig. 7 ~ Fig. 9.

![Figure 6. Adams analysis model](image1)

![Figure 7. The 7th mode deformation](image2)

![Figure 8. The 10th mode deformation](image3)

![Figure 9. The 12th mode deformation](image4)
3.3. Analysis of simulation results

Set the camshaft speed according to the actual production beat of the manipulator and carry out simulation analysis. In order to compare rigid body system and rigid flexible coupling system, the same results are put in the same graph.

The displacement of the manipulator in the vertical and horizontal directions are shown in figures 10 and 11. The displacement curve of the rigid body system is relatively smooth, and only the spring produces small vibration. The vibration displacement of rigid flexible coupling system is obviously larger, especially in the vertical direction. It can be seen that the elasticity of the guide rod has a certain impact on the operation accuracy of the manipulator.

The velocity of the manipulator in the vertical and horizontal directions are shown in figures 12 and 13. The velocity vibration amplitude of rigid flexible coupling system is about three times that of rigid system. It can be seen that the running stability of the system is worse than that of the ideal state after considering the elasticity of the guide rod, and the material with larger elastic modulus can be considered for improvement.

The acceleration of the manipulator in the vertical and horizontal directions is shown in figures 14 and 15. The acceleration vibration amplitude of rigid flexible coupling system is about from three to ten times that of rigid system. It can be seen that the elasticity of the guide rod intensifies the impact of motion in the dynamic system. In the case of higher stability requirements, dampers should be considered.

The contact forces of the two cams are shown in figures 16 and 17. The vibration amplitude of rigid flexible coupling system is several times larger than that of rigid system, especially in the vertical direction.
The vibration of contact force is easy to cause the material fatigue of cam profile and follower. Therefore, in addition to adding dampers, it is necessary to select appropriate heat treatment or surface treatment process to improve the service life of the cam.

\[ \text{Figure 14. Vertical acceleration} \]

\[ \text{Figure 15. Horizontal acceleration} \]

\[ \text{Figure 16. Contact force of cam 1} \]

\[ \text{Figure 17. Contact force of cam 2} \]

4. Conclusion
Based on the theory of rigid flexible coupling, a cam manipulator used in an automatic production line is simulated. By comparing the differences between rigid body system and rigid flexible coupling system in various dynamic performance indexes, it can be seen that the positioning accuracy and stability of manipulator movement are affected by the elasticity of components.

In the case of high accuracy requirements, the elasticity of members cannot be ignored. At the same time, the improvement measures are put forward, including replacing the material with more rigidity and increasing the damper. The simulation analysis provides the basis for the following optimization design and machining.

References
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