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Creative Combination Modeling and Simulation of Planar Linkage Mechanisms Based on SolidWorks

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Abstract

Planar linkage mechanisms are the most fundamental and widely applied transmission mechanisms in the mechanical field, whose kinematic characteristics directly determine the operational performance of mechanical equipment. Aiming at the poor effect of experimental teaching caused by wear and part loss of physical models in the Mechanical Principle Laboratory of universities, this paper takes the typical planar linkage mechanisms and creative composite mechanisms in the laboratory as the research objects, and conducts research on virtual modeling and motion simulation by using SolidWorks software and its Motion plug-in. Through mapping the dimensions of physical mechanisms in the laboratory, three-dimensional modeling and virtual assembly of eight types of planar linkage mechanisms (including gear-driven double rocker mechanism and crank-rocker double parallelogram composite mechanism) were completed. Kinematic and dynamic data such as angular velocity, angular acceleration and linear velocity of the components were obtained via simulation analysis. The simulation results show that the motion laws of the virtual mechanisms are completely consistent with those of the physical ones, and the variation laws of motion parameters that cannot be observed in physical experiments can be presented quantitatively. This research provides a virtual simulation solution for solving the problem of insufficient mechanical experimental teaching equipment in universities, and also offers a basic method for the design and performance analysis of complex linkage mechanisms.

Key words: *SolidWorks; virtual modeling; motion simulation; planar linkage mechanism*

1 Introduction

Planar linkage mechanisms are extensively used in various mechanical equipment such as engineering machinery, agricultural machinery and light industrial equipment due to their advantages of simple structure, high load-bearing capacity and diverse motion forms. They are the core teaching content of the Mechanical Principle course and also the basic research object of mechanical design. Mechanical Principle Laboratories in universities are usually equipped with physical models of planar linkage mechanisms to intuitively demonstrate the motion laws of the mechanisms. However, physical models are prone to part wear, loss and aging after long-term use, which leads to the failure to accurately achieve the predetermined motion and seriously impairs the effect of experimental teaching. Meanwhile, physical experiments only allow observing the motion state of mechanisms with the naked eye, making it difficult to obtain quantitative parameters such as angular velocity, acceleration and force of components, which cannot meet students' needs for an in-depth understanding of the kinematic and dynamic characteristics of mechanisms.

At present, domestic scholars have applied SolidWorks Motion to the simulation research of rotary tillers, cam-linkage mechanisms and other equipment. Nevertheless, systematic modeling and simulation research on typical planar linkage mechanisms in university laboratories is still scarce, and a complete

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simulation system that can directly serve experimental teaching has not yet been formed. Based on this, this paper takes eight types of typical planar linkage mechanisms in the Mechanical Principle Laboratory as the research objects to carry out virtual modeling and simulation research based on SolidWorks. Three-dimensional modeling and assembly are completed by mapping physical dimensions, motion simulation is conducted with the Motion plug-in, and the kinematic and dynamic characteristics of each mechanism are analyzed to verify the consistency between virtual simulation and physical motion. The research aims to provide a virtual simulation scheme for university mechanical experimental teaching, offer a reference for the design, optimization and performance analysis of planar linkage mechanisms, and lay a foundation for the subsequent research of complex composite linkage mechanisms.

2 Basic Theories and Simulation Principles of Planar Linkage Mechanisms

2.1 Composition and classification of planar linkage mechanisms

A planar linkage mechanism is composed of several components connected by lower pairs (revolute pairs and prismatic pairs), with all components moving in the same plane or mutually parallel planes. Its basic components include the frame, driving links, driven links and kinematic pairs. As the most fundamental planar linkage mechanism, the planar four-bar mechanism can be classified into the double crank mechanism, crank-rocker mechanism and double rocker mechanism according to the motion forms of the side links. The judgment of these mechanisms abides by the link length condition: the sum of the lengths of the shortest link and the longest link is less than or equal to the sum of the lengths of the other two links. The kinematic pairs of planar linkage mechanisms are all surface-contact lower pairs, which have the advantages of large load-bearing capacity, slight wear and easy processing and manufacturing. However, their transmission paths are long, which is prone to error accumulation, and the inertial force is difficult to balance, making them unsuitable for high-speed motion [1-4]. In practical applications, a single planar four-bar mechanism can form a composite mechanism through combination and superposition, or be integrated with gears, cams and other mechanisms to meet more complex motion requirements, such as the gear-driven double rocker mechanism and the crank-rocker double parallelogram composite mechanism.

2.2 Calculation of mechanism degree of freedom

The prerequisite for a mechanism to realize a definite motion is that the number of driving links is equal to the degree of freedom of the mechanism. The calculation formula for the degree of freedom of a planar mechanism is as follows:

$$F = 3n - (2P_L + P_H) \tag{1}$$

where n is the number of moving components, P_L is the number of lower pairs, and P_H is the number of higher pairs. In the calculation, the influences of compound hinges, local degrees of freedom and passive constraints must be excluded. Local degrees of freedom have no effect on the overall motion of the mechanism, and passive constraints are redundant constraints; both of them should be eliminated in the calculation to ensure the accuracy of the degree of freedom calculation.

2.3 Simulation principle of solid works motion

SolidWorks Motion is based on the theory of multi-body dynamics and adopts numerical methods to solve the motion equations of mechanisms, which can realize kinematic and dynamic simulation of rigid bodies. Kinematic simulation only considers the motion laws of mechanisms without taking force conditions into account, and can obtain parameters such as displacement, velocity and acceleration of components; dynamic simulation combines factors such as force, torque and inertia to analyze the force and energy consumption characteristics of mechanisms [5-7]. In the simulation process, motion constraints (including motors with constant rotational speed, constant acceleration, etc., and kinematic pairs such as revolute pairs and prismatic pairs) are first added to the mechanism. Then, loads such as gravity, external force and resistance are applied according to actual working conditions. The software solves the dynamic equations, outputs the kinematic and dynamic data of each component, and displays the data intuitively in the form of curves, providing a quantitative basis for the performance analysis of mechanisms.

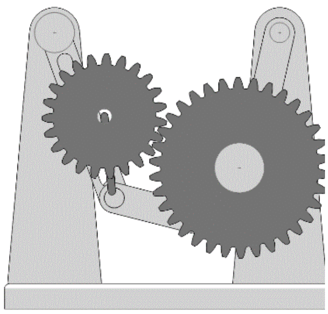
3 Modeling of Planar Linkage Mechanisms Based on SolidWorks

3.1 Modeling preparation and dimension mapping

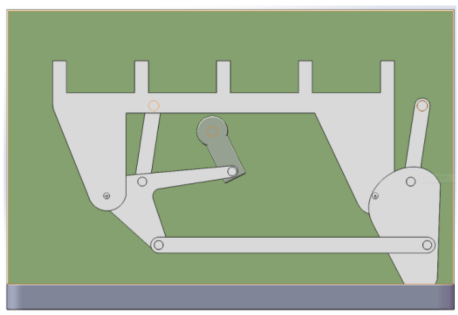
Based on the existing physical models of planar linkage mechanisms in the Mechanical Principle Laboratory, calipers, tape measures and other tools are used to map the key dimensions of each mechanism, such as component length, center distance of kinematic pairs, gear module and number of teeth. For mechanisms with inaccurate dimension measurement caused by damage, the dimensions are corrected according to the link length condition and motion laws to ensure that the kinematic characteristics of the modeled mechanism are consistent with those of the physical one. Meanwhile, for mechanisms with gears, standard involute spur cylindrical gears are selected. According to the mapped gear ratio, the module m=2, addendum coefficient h_a^*=1 and clearance coefficient c^*=0.25 are adopted, and the reference circle diameter, addendum circle diameter, dedendum circle diameter and center distance of the gears are calculated through gear design formulas [8].

3.2 Three-dimensional modeling and assembly of typical planar linkage mechanisms

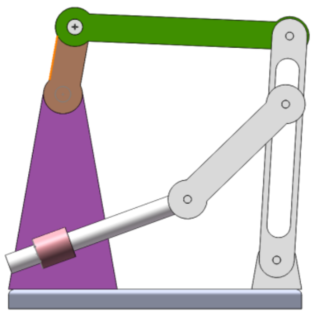
Using the Part Design module of SolidWorks, three-dimensional modeling of each component of the mechanisms is completed according to the mapped and calculated dimensions. In the modeling process, the non-critical structures of components are simplified, and the core dimensions affecting the motion of mechanisms are retained. After the completion of part modeling, virtual assembly of each component is realized by adding mating relations (coincidence, concentricity, distance, etc.) in the Assembly module, which accurately restores the connection relations and kinematic pair forms of the mechanisms and ensures that the motion of the assembly is consistent with that of the physical mechanism. In this research, modeling and assembly of eight types of typical planar linkage mechanisms are completed, including the gear-driven double rocker mechanism, crank-rocker double parallelogram composite mechanism, linear motion mechanism, gear swing rod mechanism, oscillating guide bar quick-return mechanism, plow claw telescopic mechanism, crank slider mechanism and double crank mechanism. Their assemblies are shown in Figure 1.



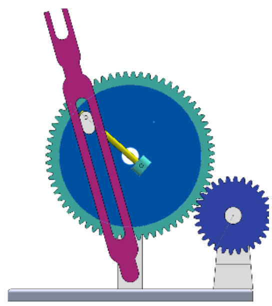
(a) Gear-driven double rocker mechanism



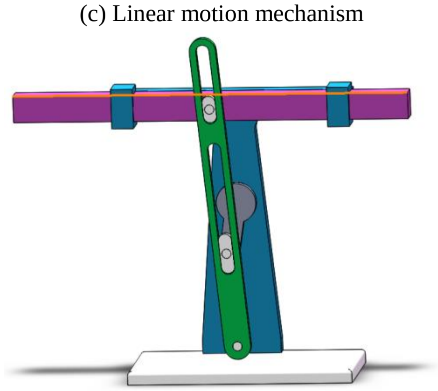
(b) Crank-rocker double parallelogram composite mechanism



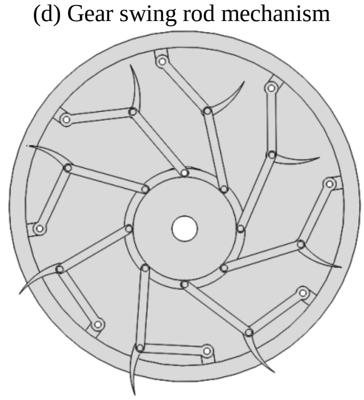
(c) Linear motion mechanism



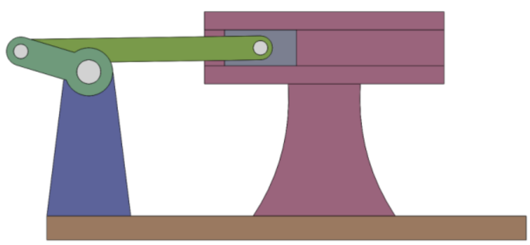
(d) Gear swing rod mechanism



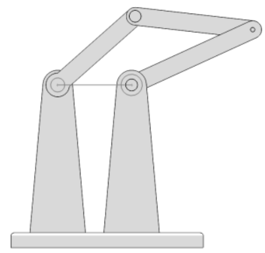
(e) Oscillating guide bar quick-return mechanism



(f) Plow claw mechanism



(g) Crank slider mechanism



(h) Double crank mechanism

Figure 1 Assemblies of planar linkage mechanisms

4 Motion Simulation and Result Analysis of Planar Linkage Mechanisms Based on Motion

4.1 Setting of simulation parameters

Simulation parameters are added to the assembly of each mechanism in SolidWorks Motion. The gravity direction is uniformly set to the negative direction of the Y-axis, and a constant-speed rotating motor is added to the driving link according to the actual motion form of the mechanism, with the motor speed set to 5 r/min or 10 r/min. For some mechanisms, a vertical downward external force is applied to the driven link according to working conditions. The simulation time is set to 10~20 s according to the motor speed to ensure that the mechanism completes at least one motion cycle, and the simulation step size is set to 0.01 s to guarantee the accuracy of the simulation results.

4.2 Simulation results and kinematic analysis

After the simulation, data such as angular velocity, angular acceleration, linear velocity, torque and energy consumption of the components of each mechanism are extracted to generate data curves. The motion laws of the mechanisms are analyzed combined with the knowledge of Mechanical Principle and Theoretical Mechanics. The core simulation results and analysis are as follows.

4.2.1 Double crank mechanism

The shortest link of this mechanism serves as the frame, which satisfies the link length condition. A motor with a rotational speed of 5 r/min is applied to the driving link, and its angular velocity is about 30 deg/s with slight fluctuations under the action of gravity. The angular velocity of the long side link of the driven part changes periodically with a period of 12 s, which is consistent with the motor speed, and the maximum angular velocity appears at 10~11 s, as shown in Figure 2.

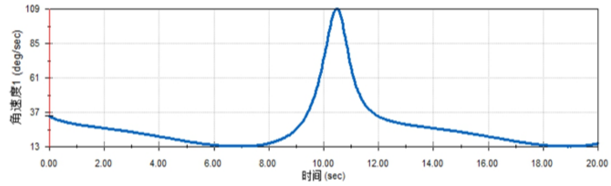


Figure 2 Angular velocity diagram of the double crank mechanism

4.2.2 Crank-rocker double parallelogram composite mechanism

This mechanism is formed by the superposition of a crank-rocker mechanism and a double parallelogram mechanism. A motor with a rotational speed of 10 r/min is added to the driving link, and its angular velocity is about 60 deg/s with the angular acceleration close to 0 during constant-speed rotation. The angular velocity of the driven rocker of the crank-rocker mechanism presents a periodic variation with a steep rise and steep fall trend. In one motion cycle, the angular velocity remains low and stable for most of the time and changes sharply in a short time, which is a typical kinematic characteristic of planar linkage mechanisms, as shown in Figure 3.

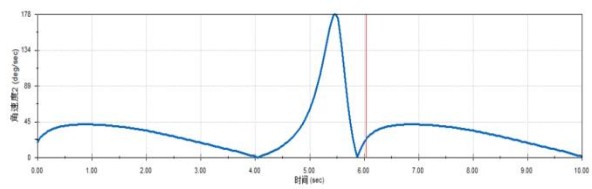


Figure 3 Angular velocity diagram of the crank-rocker double parallelogram composite mechanism

4.2.3 Oscillating guide bar quick-return mechanism

This mechanism has obvious quick-return characteristics. When the driving link rotates at a constant speed, the angular velocity of the guide bar changes periodically at a non-uniform speed, and the maximum angular velocity appears at the position where the driving link is coincident with the axis of the guide bar. The analysis of its motion mechanism shows that the component of the pin velocity on the driving link in the vertical direction of the guide bar is the effective linear velocity of the guide bar, and the closer the pin is to the rotating point on the guide bar, the greater the angular velocity of the guide bar. These two factors jointly result in the quick-return motion of the guide bar, as shown in Figure 4.

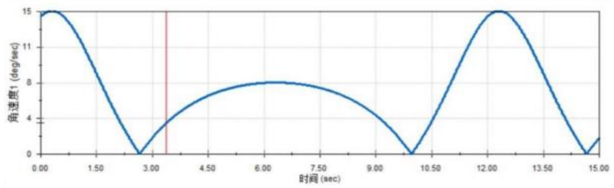


Figure 4 Angular velocity diagram of the oscillating guide bar quick-return mechanism

4.2.4 Crank slider mechanism

When the driving link of the crank slider mechanism rotates at a constant speed, the angular velocity of the connecting rod changes in a sinusoidal function law. The reason is that the component of the linear velocity of the driving link in the vertical direction of the connecting rod is the effective linear velocity of the connecting rod, and this component varies sinusoidally with the rotation of the driving link, as shown in Figure 5.

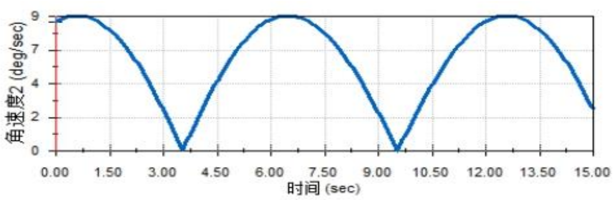


Figure 5 Angular velocity diagram of the crank slider mechanism

5 Conclusions

Taking the planar linkage mechanisms in the Mechanical Principle Laboratory as the research objects, this paper conducts research on virtual modeling, assembly and Motion simulation based on SolidWorks, completes the systematic analysis of eight types of typical mechanisms, and draws the following conclusions:

(1) The SolidWorks three-dimensional model established on the basis of physical mapping dimensions and gear design formulas accurately restores the structural characteristics of the physical mechanism in terms of the connection relations and kinematic pair forms of the assembly. The motion laws of the virtual mechanism are completely consistent with those of the physical one, which verifies the accuracy of virtual modeling.

(2) SolidWorks Motion can accurately obtain quantitative parameters of planar linkage mechanism components, such as angular velocity, angular acceleration, linear velocity, torque and energy consumption. These parameters cannot be observed in physical experiments, which makes up for the deficiencies of physical experiments and provides data support for an in-depth understanding of the kinematic and dynamic characteristics of mechanisms.

(3) The motion parameters of all planar linkage mechanisms change periodically, and there is a strict corresponding relationship between angular velocity, angular acceleration and torque, which is in line with the basic laws of Mechanical Principle and Theoretical Mechanics, verifying the scientificity of simulation results.

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