DESIGN AND ANALYSIS OF GUIDE MECHANISM DRIVEN BY LIMACON GEAR

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The paper proposes a new guide mechanism, the mechanism is basically formed by two combined mechanisms: a scotch yoke mechanism, driven by Limacon gear. The kinematic mathematical model of scotch yoke mechanism and high-order modified Limacon gear are derived, a software for analyzing the guide mechanism driven by Limacon gear is developed in MATLAB, a modified genetic algorithm is used to optimize the mechanism, The objective is lowering the average velocity of the rod within the effective range.

By analyzing the kinematics of the guide mechanism, and comparing the speed of rod with and without Limacon gear, the velocity curve of the rod exhibits an approximate constant velocity motion law for a long time during the reciprocating stroke process, verifying the feasibility of the proposed mechanism.

Keywords: guide mechanism, Limacon gear, approximately uniform velocity, genetic algorithm

1. Introduction

The forming device of the coarse spinning carding machine [1]winds the coarse yarn output from the washboard into a coarse yarn cake with a certain thickness, and its forming shape directly affects the feeding of the subsequent fine yarn machine. [2]The motion of the forming device consists of the linear reciprocating motion of the guide mechanism and the rotary motion of the drum. In order to obtain a high-

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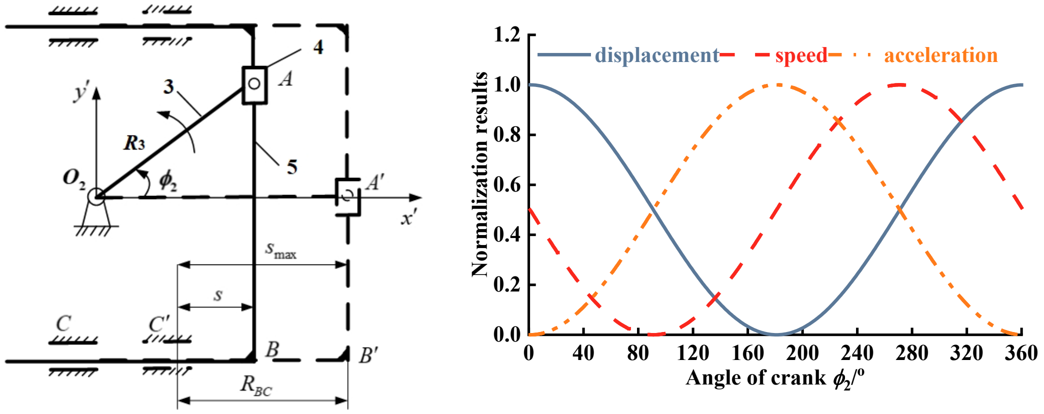
quality roving cake shape, the rod of the guide mechanism needs to meet the performance requirements of uniform reciprocating linear motion within a certain range of motion. [3]

At present, a combination of elliptical gears with a 1:1 order ratio, cylindrical gears with a 2 transmission ratio, and scotch yoke mechanism [5]was commonly used to drive the rod for reciprocating linear motion, achieving a relatively smooth guide motion and improving the forming shape of the roving cake to a certain extent. However, using only elliptical gears to drive the guide rod cannot meet the ideal guide motion law, and the next stage after the elliptical gears is a cylindrical gear with a 2 transmission ratio, which has a complex structure and seriously affects the overall transmission performance.[7]

In response to the above issues, this paper proposed a combination mechanism of high-order modified Limacon non-circular gear with scotch yoke mechanism to enable the guide bar component to achieve constant reciprocating linear motion over a long range of motion. A kinematic mathematical model of the mechanism is established, and a kinematic characteristic auxiliary analysis software for the mechanism is developed in MATLAB. A modified genetic algorithm is used to optimize the mechanism and select a set of optimal parameters. And compare the speed of rod with and without Limacon gear, verifying the feasibility of the proposed mechanism.

2. Scotch yoke mechanism

Scotch yoke mechanism[8] is the mechanism which can realize sinusoidal motion law, Fig.1 (a) and (b) show the schemes of Scotch yoke mechanism and the normalized motion characteristics of the output of Scotch yoke mechanism. Scotch yoke mechanism is schematically represented as four members: frame, links 3, 4 and 5 are, respectively, the crank, the slider and the rod. Crank (link 3) rotation is the input of this mechanical system, while the reciprocating linear motion of the rod (link 5) is the output, and the rod of driven mechanism undergoes a reciprocating linear motion with a sinusoidal motion pattern within one transmission cycle. The dashed line in the Fig.1 (a) represents the Scotch yoke mechanism corresponding to the maximum displacement of the rod, while the solid line represents the Scotch yoke mechanism corresponding to any given moment.



(a) Schemes of Scotch yoke mechanism (b) motion characteristics of Scotch yoke mechanism

Fig.1 Scotch yoke mechanism

Analyzing the motion characteristics of Scotch yoke mechanism, by referring to Fig.1 (a), the position equation of the rod of Scotch yoke mechanism are the following:

The position coordinates of point A on slider 4 can be expressed as:

$$\begin{cases} x_A = R_3 \cos \phi_2 \\ y_A = R_3 \sin \phi_2 \end{cases} \tag{1}$$

where R_3 and ϕ_2 are, respectively, the length and angle of the crank (link 3).

Due to the reciprocating linear motion of rod (link 5) of the driving mechanism, the position coordinates of point B on rod can be represented as $x_B = x_A$ (2)

The position coordinates of point C on rod (link 5) can be expressed as:

$$x_C = x_A - R_{BC} \tag{3}$$

The displacement s of the rod (link 5) of the driving mechanism can be expressed as:

$$s = R_3 \cos(\phi_2) \tag{4}$$

By taking the first derivative of time t at both ends of Eq.4, the equation for the velocity $\dot{s}$ of the rod (link 5) can be expressed as:

$$\dot{s} = -\Omega(\phi_2) R_3 \sin \phi_2 \tag{5}$$

where $\Omega(\phi_2)$ is angular velocity of crank 3.

By taking the first derivative of time t at both ends of Eq.5, the equation for the acceleration $\ddot{s}$ of the rod (link 5) can be expressed as:

$$\ddot{s} = -A(\phi_2) R_3 \sin(\phi_2) - \Omega(\phi_2)^2 R_3 \cos(\phi_2) \tag{6}$$

where $A(\phi_2)$ is angular acceleration of crank 3.

2 Limacon gear mechanism

As shown in Fig.2, the pitch curve around the rotation center O_1 is Limacon gear, and the pitch curve around the rotation center O_2 is its conjugate gear. Parameters R_1, ϕ_1, R_2 and ϕ_2 are, respectively, radial diameter of Limacon gear[9], angle of Limacon gear, radial diameter and angle of conjugate gear , a is the gear center distance, Limacon gear is driven by motor to rotate at a constant speed ω, due to the time-varying pitch to diameter ratio of the Limacon gear and its conjugate gear, the conjugate gear rotates at a variable speed $\Omega(\phi_2)$.

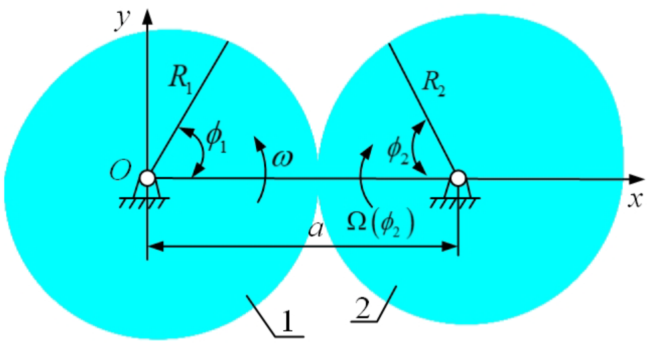


Fig.2 Schemes of Limacon gear mechanism

Referring to the schemes in Fig.2, the pitch curve of Limacon gear [10] is expressed by the following equation:

$$R_1(\phi_1) = \begin{cases} b\cos(n_1 m_{11}\phi_1) + l & \phi_1 \in [0, \pi/n_1 m_{11}) \\ b\cos(n_1 m_{12}(2\pi/n_1 - \phi_1)) + l & \phi_1 \in [\pi/n_1 m_{11}, 2\pi/n_1] \end{cases} \tag{7}$$

where b is the diameter of pitch curve's generated circle, l is the fixed length, n_1 is the order of Limacon gear, m_{11} and m_{12} are the modified coefficient of first and second sections of the Limacon gear, respectively, to ensure the pitch curves of modified

Limacon gear closed, the modified coefficient m_{12} of second sections of the Limacon gear must be $m_{12} = m_{11}/(2m_{11}-1)$.

According to the condition for continuous movement, the pitch curve of Limacon gear and its conjugate gear are both closed. Which means when conjugate gear rotates n_2 times, the Limacon gear turns n_1 times, the following equation must be satisfied:

$$\frac{2\pi}{n_2} = \int_0^{\frac{2\pi}{n_1}} \frac{1}{\tau(\phi_1)} d\phi_1 = \int_0^{\frac{2\pi}{n_1}} \frac{R_1(\phi_1)}{a - R_1(\phi_1)} d\phi_1 \tag{8}$$

where $\tau(\phi_1)$ is the transmission ratio of Limacon gear. By solving the Eq.8, the distance a of eccentric gear and its conjugate gear can be deduced.

The mathematical model of pitch curve $R_2(\phi_2)$ and rotating angle ϕ_2 of conjugate gear are

$$\begin{cases} R_2(\phi_2) = a - R_1(\phi_1) \\ \phi_2 = \int_0^{\phi_1} \frac{1}{\tau(\phi_1)} d\phi_1 = \int_0^{\phi_1} \frac{R_1(\phi_1)}{a - R_1(\phi_1)} d\phi_1 \end{cases} \tag{9}$$

According to the principle of gear meshing, once ω and $\Omega(\phi_2)$ (or $R_1(\phi_1)$ and $R_2(\phi_2)$) are known, the variable gear transmission ratio of Limacon gear could be evaluated as a function ϕ_1 in the form

$$\tau(\phi_1) = \frac{\omega}{\Omega(\phi_2)} = \frac{R_2(\phi_2)}{R_1(\phi_1)} \tag{10}$$

3 Guide mechanism driven by Limacon gear

3.1 Principle of guide mechanism

According to the textile process of forming yarn into yarn cakes, the rod needs to meet the requirements of achieving approximately constant speed guide performance within a certain range of motion. In this paper, a combination of first-order and second-order conjugate Limacon non-circular gear pairs and Scotch yoke mechanism are used for transmission to achieve approximately constant speed motion of the guide.[11] The guide mechanism is simplified as shown in Fig.3. The guide mechanism is basically formed by two combined mechanisms: a scotch yoke mechanism, driven by a Limacon gear pair. Limacon gear 1 rotation is the input of this mechanical system, while the reciprocating linear motion of rod is the output. In Fig.3 the mechanism is schematically represented as four members: frame, Limacon gear 1 and its conjugated gear 2, and links 3, 4 and 5 are, respectively, the crank, the slider and the rod of the driving mechanism.

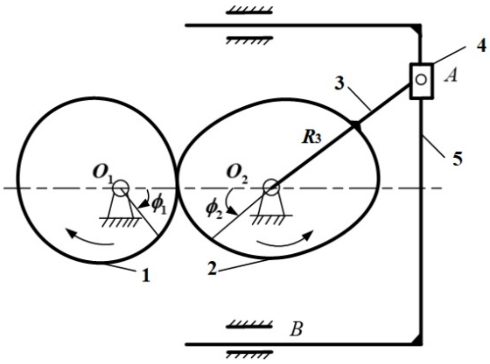


Fig.3 Schemes of guide mechanism driven by Limacon gear

3.2 Software for analyzing the guide mechanism

For the sake of analyzing the guide mechanism driven by Limacon gear, a visual design platform of this mechanism is developed, as shown in Fig.4. The effect factor on motion characteristics of guide mechanism can be analyzed by the software, and user can obtain the design parameters of guide mechanism for the design requirement.

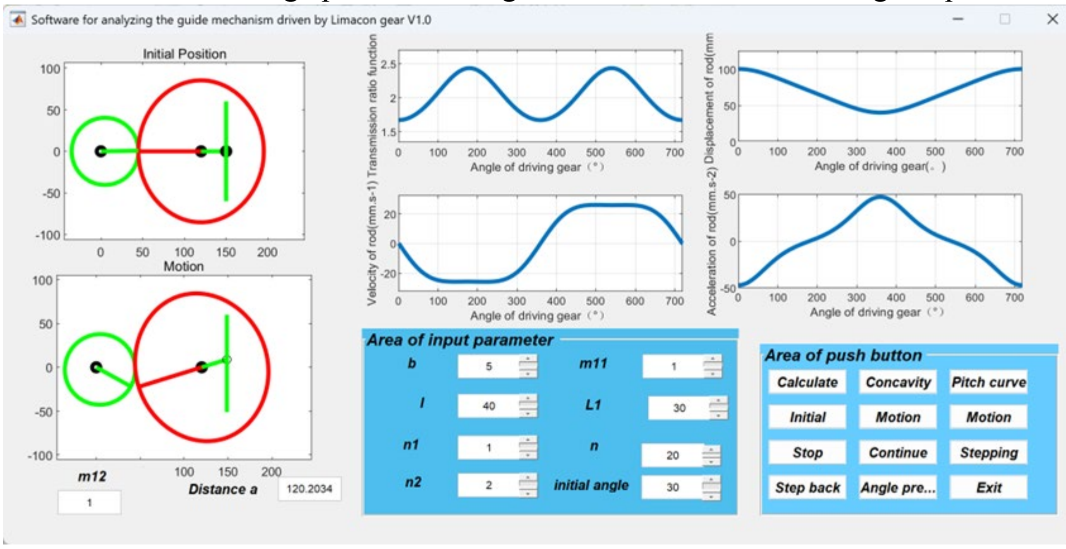


Fig.4 Software for analyzing the guide mechanism

4 Optimization method

A modified genetic algorithm [12] is to optimize the guide mechanism in Fig.3, with the constant speed motion characteristics of the rod as the objective function and the Limacon non-circular gear transmission characteristics as the constraint condition, and then searching for mechanism parameters that meet the motion characteristics of the forming mechanism of the roving carding machine.

Basic parameters of modified genetic algorithm: Initial population size: 20, Genetic algebra: 100, Binary digits of variables: 20, Individual selection ratio between populations: 0.9, Cross probability: 0.8, Mutation probability: 0.1.

4.1 Objective function

To study the constant velocity characteristics of the rod, the mean square error of velocity is introduced as the objective function of this optimization. The average velocity of the rod within the effective range is set to $\bar{\dot{s}}$ [13], with a numerical value of $\bar{\dot{s}} = \sum_{i=0}^{N} \frac{\dot{s}_i}{N}$, where N is the number of equal points calculated. The mean square error equation of the guide bar's velocity can be expressed as:

$$F = \sqrt{\sum_{i=1}^{N} (\dot{s}_i - \bar{\dot{s}})^2 / N} \tag{11}$$

4.2 Optimization parameters.

Analyzing the mathematical model of the guide mechanism driven by Limacon gear, it is known that the motion characteristics of the rod depend on the parameters of the Limacon non-circular gear pairs. Therefore, the optimized parameter equation is:

$$x_p = [b, l, m_{11}] \tag{12}$$

4.3 Constraint equation

In order to ensure the smooth transmission of non-circular gear pairs, non-circular gears should meet the requirement of maintaining convexity[14], constraint equation can be expressed as:

$$\begin{cases} 1+\tau(\phi_1)+\dfrac{\tau^2(\phi_1)}{d\phi_1^2}\geq 0 \\ 1+\tau(\phi_1)-\tau(\phi_1)\dfrac{\tau^2(\phi_1)}{d\phi_1^2}+\left(\dfrac{\tau(\phi_1)}{d\phi_1}\right)^2\geq 0 \end{cases} \tag{13}$$

5. Kinematic analysis of guide mechanism driven by Limacon gear

Using a modified genetic algorithm to optimize and round the structural parameters, the optimal result is:

$$[b,l,m_{11},n_1,n_2,R_3]=[5\text{mm},40\text{mm},1,1,2,30\text{mm}] \tag{14}$$

Fig.5 shows comparison of rod speed with and without Limacon gear, the dashed line (cyan line) represents the speed curve of the guide rod driven by cylindrical gears, the velocity curve of the rod exhibits a sinusoidal characteristic; the solid line (red line) represents the speed curve of the guide rod driven by Limacon gears, the velocity curve of the rod exhibits an approximate constant velocity motion law for a long time during the reciprocating stroke process.

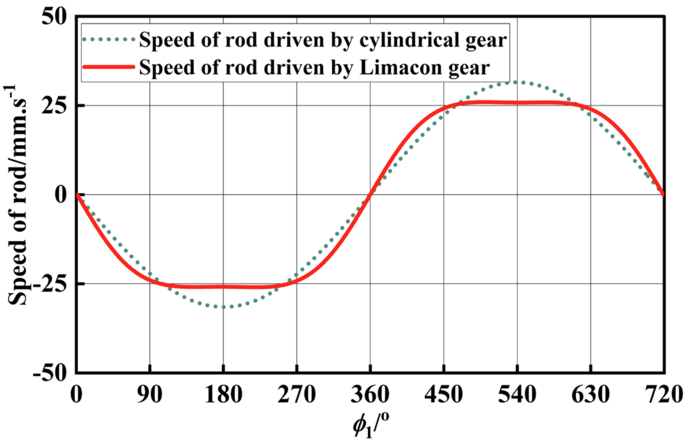


Fig.5 Comparison of rod speed

6. Conclusions

In this paper a method for the kinematic optimization of guide mechanism has been proposed. The guide mechanism is basically formed by two combined mechanisms: Scotch yoke mechanism, driven by a Limacon gear mechanism.

At first, the motion characteristic equations of rod of Scotch yoke mechanism have been derived by means of a kinematic analysis of the mechanism, and the mathematical model of high-order modified Limacon gear has been derived by the geometric relationship, the motion characteristic of combination series mechanism has been performed, a software for analyzing the guide mechanism driven by Limacon gear has been developed, the guide mechanism driven by Limacon gear has been optimized by using an modified genetic algorithm.

By analyzing the kinematics of the guide mechanism, and comparing the speed of rod with and without Limacon gear, the velocity curve of the rod exhibits an approximate constant velocity motion law for a long time during the reciprocating stroke process.

The software developed provides a convenient design tool for the analysis of guide mechanism driven by Limacon gear pairs.

Acknowledgment

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: this work was supported by the science research project of department of education of Zhejiang province, china (grant number: Y202249437), and the Public Welfare Technology Application Research Project of Jinhua (grant number: 2022-4-069), and the science research project of Xingzhi college (grant number: ZC304924006).

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