Simulation Analysis of Iron Roughneck's Stretching Device based on MATLAB and Adams

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Abstract. In this paper the composition and working principle of stretching device for arm iron roughneck are introduced, and the kinematic model of the mechanism is established. The kinematic parameter curves of each necessary component are got by using complex vector method and solving the model with MATLAB. The kinematics simulation analysis of the virtual prototype of the iron roughneck's stretching device is carried out by Adams, and then the kinematic parameter curves of each component are obtained, and compared with the curve obtained by MATLAB. The results show that the performance of iron roughneck stretching device is good. Most of the parameter curves calculated by MATLAB are consistent with the results of Adams simulation, and the influencing factors of the curve inconsistency are analyzed.

1. Introduction

Arm iron roughneck is a kind of petroleum mechanical equipment with complex mechanical structure and high degree of automation. The stretching device is one of the important components of the arm iron roughneck. Most of the arm iron roughnecks need to realize the translational movement of the iron roughneck's clamp body through the stretching device. The movement and force characteristics of the stretching device have an important impact on the performance of the whole machine. Usually the traditional design method needs to be tested after machining the prototype to find out the deficiencies of the design, and then back to the design stage for modification and optimization, which will spend a lot of time and materials. By using the method of theoretical analysis and simulation analysis of virtual prototype, it is more convenient to find the design deficiencies and improve the design, reduce the development cycle, and save materials and processing costs. In this paper, MATLAB and Adams are used to calculate and simulate the stretching device of iron roughneck, which are verified by each other, so as to obtain more reliable motion parameters of the mechanism, and provide the basis for the subsequent improvement design.[1]

2. Iron Roughneck’s Stretching Device

2.1. Composition

Figure 1(a) shows the layout of the stretching device on the iron roughneck. The stretching device is consisted of the stretching arm assembly, the upper pulley, the lower pulley, the stretching cylinder, and the support arm, and etc. The stretching device is connected with the guide column assembly through the upper pulley and the lower pulley, and is connected with the clamp body support through the
stretching arm assembly. Figure 1(b) shows the mechanism schematic diagram of the stretching device, and H represents the barycenter of the clamp body [2].

Figure 1. (a): layout diagram of stretching device on iron roughneck, (b) mechanism sketch. In 1.(a):1- guide column assembly; 2- lifting hydraulic cylinder; 3- upper pulley; 4 - lower pulley; 5- stretching cylinder; 6- stretching arm assembly; 7- supporting arm; 8- clamp body stents.

2.2. Working Principle
The stretching device of the iron roughneck is mainly used to realize the horizontal movement of the iron roughneck's clamp body. As shown in figure 1 (a), there are two sets of hydraulic cylinders, which control the lifting and extending actions of the iron roughneck respectively. When the stretching cylinder is locked, the freedom of the stretching device is 0, and the mechanism will remain stationary. At this time, if the lifting cylinder is driven, the upper and lower pulley will be driven to slide on the guide column assembly at the same time to realize the lifting action of the iron roughneck. When the stretching device works, the lifting cylinder is locked and down pulley is fixed. The iron roughneck stretching arm adopts a parallelogram mechanism and is hinged with the upper pulley, and the supporting arm is hinged with the down pulley and the stretching arm. If the hydraulic cylinder is driven, it will drive the upper roller of the iron roughneck to slide on the guiding column. The upper trolley will extend and recover the extension arm, and then drive the clamp bracket and the work clamp body mounted on it to realize the expansion movement. This is the extension stage of the iron roughneck, and this stage is the work stage studied in this paper.

Figure 2. (a): hydraulic cylinder two-stage linkage group (b): RRR two-stage linkage group.

3. MATLAB Theoretical Calculation
3.1. Establish the Kinematic Model of the Mechanism
Complex vector method has advantages over other methods in dealing with vector rotation, derivation and equation elimination. Therefore, the complex vector method is used to analyze the stretching mechanism. The stretching device of the iron roughneck can be simplified into a plane connecting linkage mechanism as shown in figure 1(b). The global complex vector coordinate system is established

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at point A, and the linkage 1 is removed, and the constraint equations (1) of double hinged bar 1 are established, then the velocity (2) and acceleration (3) of point A and B can be obtained as follow:

\[
\begin{align*}
\text{f} &= (B_x - A_x)^2 + (B_y - A_y)^2 - L_{AB} = 0 \quad (1) \\
\dot{\text{f}} &= 2(B_x - A_x)(\dot{B}_x - \dot{A}_x) + 2(B_y - A_y)(\dot{B}_y - \dot{A}_y) = 0 \quad (2) \\
\ddot{\text{f}} &= 2(B_x - A_x)(\ddot{B}_x - \ddot{A}_x) + 2(B_y - A_y)(\ddot{B}_y - \ddot{A}_y) + 2(\dot{B}_x - \dot{A}_x)^2 + 2(\dot{B}_y - \dot{A}_y)^2 = 0 \quad (3)
\end{align*}
\]

Assuming that the upper pulley 5 is the original moving part, and its initial position, velocity and acceleration are \(C(C_x, C_y)\), \(\dot{C}(\dot{C}_x, \dot{C}_y)\), and \(\ddot{C}(\ddot{C}_x, \ddot{C}_y)\). Split the iron roughneck’s stretching device as shown in figure 2, including one RRR type two-stage linkage group and one hydraulic cylinder two-stage linkage group. The displacement, velocity and acceleration of each component can be obtained by establishing complex vector equations of the two linkage groups and analyzing their geometric relationship[3-4]. By calculating the position vector diameter, velocity vector diameter, acceleration vector diameter of point G and F, and the cylinder stretch length, stretch speed and stretch acceleration \((L_{FE}, L_{EF}, L_{FG})\), the displacement, velocity and acceleration of point E and D, as well as the angle, angular velocity and angular acceleration of linkage 4 and 6 can be solved. In the same way, the displacement, velocity and acceleration of point B and C, and the angle, angular velocity and angular acceleration of linkage 2 and 3 are obtained. Taking point C as an example, the expressions of velocity (4) and acceleration (5) as follows:

\[
\begin{align*}
\dot{C}_x &= \ddot{G}_x - L_{CG} \Phi_2 \sin \Phi_2 = G_x - \Phi_2(C_y - G_y) \quad (4) \\
\dot{C}_y &= \ddot{G}_y + L_{CG} \Phi_2 \cos \Phi_2 = \ddot{G}_y + \Phi_2(C_x - G_x) \\
\ddot{C}_x &= \dddot{G}_x - \Phi_2(C_y - G_y) - \Phi_2^2 (C_x - G_x) \\
\ddot{C}_y &= \dddot{G}_y + \Phi_2(C_x - G_x) + \Phi_2^2(C_y - G_y) \quad (5)
\end{align*}
\]

3.2. Model Calculation and Solution

According to the mathematical models of the two linkage groups, the motion analysis and calculation of the plane mechanism of the stretching device can be carried out. The constraint equations of \(C\), \(\dot{C}\) and \(\ddot{C}\) expressed by point B are obtained as follows:

\[
\begin{align*}
\text{f} &= \text{f}(C) = 0 \quad (6) \\
\dot{\text{f}} &= \dot{\text{f}}(C) = 0 \quad (7) \\
\ddot{\text{f}} &= \ddot{\text{f}}(C) = 0 \quad (8)
\end{align*}
\]

Equations (6), (7) and (8) are all univariate and nonlinear equations, which are difficult to get the analytical solutions directly, so the numerical approximation method is used to calculate the approximate solution. In order to obtain the kinetic characteristics of the stretching device, the action process of the mechanism needs to be discretized. The motion parameters of the original moving part are chosen with different values in turn, so as to solve the motion of the mechanism in different positions and motion states. The motion of the mechanism can be obtained by fitting the discrete points of each motion parameter. MATLAB is used to calculate and solve the kinematics of the iron roughneck’s stretching device. All the length and geometric relationship of linkages in the mechanism are design parameters, and the motion parameters of all the motion pairs externally connected to the frame can also be determined. According to the speed requirements of the mechanism, the motion parameters of the driving hydraulic cylinder can be set. All of these parameters above can be regarded as known values in the calculation, and these parameters are sorted out in table 1. The stroke design parameters of the stretching hydraulic cylinder range from 1027mm to 1405mm, and within this range, the cylinder stretching is calculated every 20mm. The curves of some calculated results are shown in Fig. 3~9.
It can be seen from figures 3 and 4, with the change of the hydraulic cylinder stretching, the displacement of the clamp body barycenter (point H) occurs mainly in the x direction (horizontal direction) while a little in the y direction (vertical direction). From figures 3~9, it can be seen that the motion parameters and extension motion parameters of the barycenter H change gently, and the displacement and angle meet the working requirements, which proved that the design is reasonable.

Table 1. Parameters of stretching device.

| parameter | value  | parameter | value  |
|-----------|--------|-----------|--------|
| $L_{AB}$  | 1015mm | $A_x$     | 0      |
| $L_{CG}$  | 2030mm | $A_x$     | 0      |
| $L_{BI}$  | 1015mm | $\dot{A}_x$ | 0      |
4. Adams Simulation Analysis

Based on the theoretical analysis and calculation, the movement of the stretching device is simulated and analyzed by using Adams [5]. On the one hand, the motion characteristics of the mechanism can be obtained through simulation, and the correctness of the theoretical calculation can be verified by comparing it with the previous calculation results. On the other hand, compared with the theoretical calculations, the simulation analysis has a lower degree of simplification and assumption of the model, so more realistic and comprehensive analysis results can be obtained [6]. Figure 10 shows the speed drive curve of the stretching cylinder, and Figure 11–14 are some important motion parameter curves. Comparing the curve simulated in Adams with that calculated by MATLAB, it can be seen that the stretching angle curve and barycenter trajectory curve of the stretching device in Figure 11 and Figure 12 are mainly the same as the calculation results of MATLAB. Compared with the corresponding MATLAB calculation results, Figures 13 and 14 are different at the beginning and the end of the curve, the reason is that the speed control mode of “accelerate-constant- deceleration” is adopted for the drive of the cylinder in Adams, but the speed of hydraulic cylinder remains unchanged in MATLAB.

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5. Conclusion

Compare the above analysis curves, it can be seen that the designed iron roughneck's stretching device has good kinematic performance, and the displacement of the clamp body barycenter in the vertical direction is small, and working process is stable, which meets the working requirements. The result of MATLAB solution is almost consistent with that of Adams simulation analysis during working, which verified the validity of the results.

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