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DYNAMIC SIMULATION AND VELOCITY ADJUSTMENT OF MECHANISM BASED ON MATLAB

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ABSTRACT

In order to improve longevity, efficiency and working quality of machinery, taking the six-bar mechanism as example, the velocity fluctuation of six-bar mechanism and its adjustment method are studied. At first, an equivalent dynamic model of six-bar mechanism was established with the vector loop equations and kinematic and dynamic characteristics were analyzed based on the model. Then kinematic and dynamic simulation of six-bar mechanism was carried out with software Matlab. The simulation results reveal the real movement regularity of six-bar mechanism of shaper in the stable operation stage. By comparing the simulation results with theoretical calculation, the validity of this method was verified. Finally, the flywheel which can store and release energy was used to adjust the periodic velocity fluctuation. The simulation results with or without flywheel show that the flywheel is of considerable adjustment effect on periodic velocity fluctuation. The peak value of angular velocity and angular acceleration of equivalent component were decreased by 11.3% and 99.57% respectively, thus to improve movement stability. This method proposed in the paper has universal significance for the general mechanism analysis and design.

Keywords: *Matlab; Six-Bar Mechanism; Simulation; Velocity Fluctuation; Adjustment*

1. INTRODUCTION

To analyze mechanical movement and force, we generally assume that the motion of driver is known and its velocity is constant. In fact, the characteristics of driving part is not only determined by itself, but also depended on the external force acting on the machinery, the quality, size, rotational inertia of each component, spatial position of mechanism and other factors. Therefore, in order to analyze precisely motion and forces about the mechanism, it is necessary to determine the real operation condition of the driving component [1]. Due to the change of driving force and impedance force will cause velocity fluctuation, thus a pair of additional dynamic pressures are generated in the kinematic pair, and lead the mechanical system to vibrate. Because mechanical vibration play an important role in the longevity, efficiency and performance of machinery, it is necessary to study the regulation of mechanical velocity fluctuation and how to adjust it [2-4]. Literature [5] describes the characteristics of the rotational velocity fluctuation of crankshafts according to different type of diesel engine. In literature [6] a velocity-adjusted mechanism is designed and it illustrates that flywheel has an evident effect on velocity fluctuation. Literature [7] proposed a method about simulation and optimization of six-bar mechanism of shaper based on ADAMS. In the paper, firstly, the equivalent dynamical model of six-bar mechanism is established with closed vector loop equations to analyze the equivalent rotational inertia and equivalent torque. Secondly, the movement simulation has been carried out using Matlab [8], and the correctness of the simulation result is verified by comparison with the theoretical calculation. Finally, the flywheel which can store and release energy is used to adjust the periodic velocity fluctuation and reduce the mechanical vibration evidently.

2. THE ESTABLISHMENT OF DYNAMICAL EQUATION

The real motion regulation of mechanical system depends on such factors as the external forces acting on it, the size, quality and rotational inertia of its components, its position and so on. Usually the motion equation of a mechanical system is formed according to the kinetic energy theorem. Practically, most of mechanisms are the single-freedom and planar-linkage mechanism which can be called simple mechanism. For this type of simple mechanism, to investigate the movement regularity of its components, we just determine the movement regularity of its equivalent component. In order to

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ensure that the original movement regulation of the mechanical system is not changed, this method requires that the external force and (or) torque are transformed into so-called equivalent force and (or) torque acted on the equivalent component. Then the movement equations of equivalent component are established to study the regulation of original mechanism.

For the convenience of calculation and simulation, taking a six-bar mechanism of shaper that is a single freedom system as an example (Fig.1). Crank AB is the driving link. It was driven by a motor. The PA is balance block. When crank AB rotates, slider 2 drives swinging lever 3 to swing, then the power transmits from swinging lever 3 through link 4 to drive plough head 5 to move reciprocally. This is the major cutting process. Firstly, the equivalent dynamical model of the above six-bar mechanism is established and shown in Fig.2.

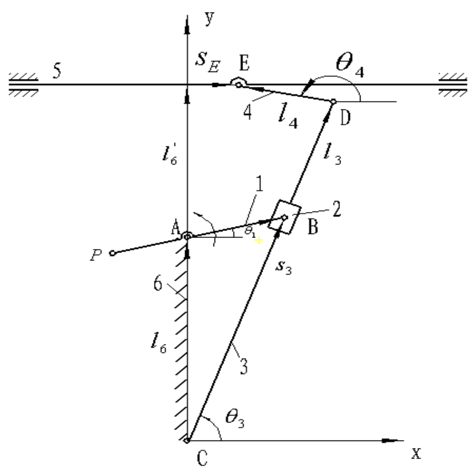

Fig.1 The Kinematic Sketch Of Six-Bar Mechanism

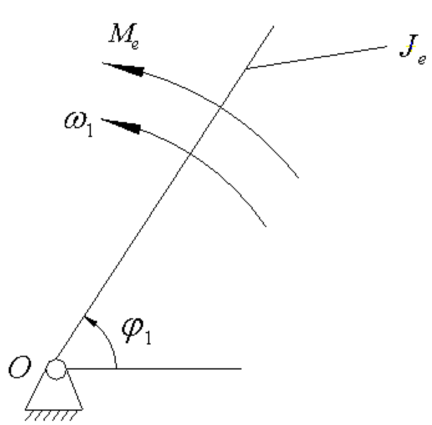

Fig.2 The Equivalent Dynamical Model

The general formula of equivalent moment of inertia J_e [9] is,

$$J_e = \sum_{i=1}^{n}[m_i(\frac{\upsilon_{si}}{\omega_1})^2 + J_{si}(\frac{\omega_i}{\omega_1})^2]$$

(1)

The general formula of equivalent torque M_e is,

$$M_e = \sum_{i=1}^{n}[F_i \cos\alpha_i(\frac{\upsilon_{si}}{\omega_1}) \pm M_i(\frac{\omega_i}{\omega_1})]$$

(2)

There into,

n is the number of active component in the mechanical system;

M_i is the torque on component i;

F_i is the force on component i;

m_i is the quality of component i;

J_{si} is the moment of inertia of component i to its center of mass;

υ_{si} is the velocity of the center of mass of component i;

α_i is the angle of F_i and υ_{si};

ω_i is the angular velocity of component i;

ω_1 is the angular velocity of the equivalent component;

φ_1 is the rotational angle of the equivalent component.

Seen from formula (1), the equivalent moment of inertia is determined with the square of velocity ratio(ω_i/ω_1). As the quality and moment of inertia of each component in the mechanical system are constant, J_e is merely a function related to the mechanism position. From formula (2), the equivalent moment M_e is not only dependent on the external force or torque acting on the

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mechanical system, but also related to the velocity ratio. Because the driving torque on the driving part of six-bar mechanism is a function of the volocity and working load is a function of the position of the mechanical system, the equivalent moment of inertia is a function of the position and velocity of equivalent component.

If ϕ_t, ϕ_{t+1} stand for the angles of rotation at the time t, t+1, the angle increment is $\Delta\phi_t = \phi_{t+1} - \phi_t (t = 0,1,2,\cdots n)$. Then the instantaneous angular velocity at the time t is,

$$\omega_{t+1} = \frac{M_e(\phi_t,\omega_t)\Delta\phi}{J_t\omega_t} + \frac{3J_t - J_{t+1}}{2J_t}\omega_t \qquad (3)$$

The instantaneous angular acceleration a_t is,

$$a_t = \frac{\omega_t d\omega_t}{d\phi_t} \qquad (4)$$

Here, $d\omega_t = \Delta\omega_t = \omega_{i+1} - \omega_t$, $d\phi_t = \Delta\phi_t = \phi_{t+1} - \phi_t$.

Based on the analysis above, we can conclude that it is necessary to determine the angular velocity, the angular acceleration, the equivalent moment of inertia and the equivalent force of the equivalent component at any time before movement simulation.

3. THE ESTABLISHMENT OF CLOSED-LOOP VECTOR EQUATION

In order to conduct movement analysis on mechanism, firstly the rectangular coordinate system is established as shown in Fig.1, in which the components are expressed as rod-vectors. Those vectors constitute two enclosed graphics, ABCA and CDEGC, on which two closed vector equations of mechanism are built as follows,

$$\begin{cases} \vec{l}_6 + \vec{l}_1 = \vec{s}_3 \\ \vec{l}_3 + \vec{l}_4 = \vec{l}_6^{\,'} + \vec{s}_E \end{cases} \qquad (5)$$

The formula (5) can be written in a form of coordinate projection,

$$\begin{cases} l_1\cos\theta_1 = s_3\cos\theta_3 \\ l_6 + l_1\sin\theta_1 = s_3\sin\theta_3 \end{cases} \qquad (6)$$

$$\begin{cases} l_3\cos\theta_3 + l_4\cos\theta_4 = s_E \\ l_3\sin\theta_3 + l_4\sin\theta_4 = l_6^{'} \end{cases} \qquad (7)$$

We use Matlab to solve the system of equations, and then obtain such variables as θ_3, θ_4, S_3 (the displacement of slider 2 along swing rod 3), S_E (displacement of plough head E).

4. SOLUTION OF VELOCITY RATIO (ω_i/ω_1)

Because the ratio is also position function, we reuse the closed-loop vector equation to get the velocity ratio. The derivation of equations (6), (7) to time is,

$$\begin{cases} l_1\omega_1\cos\theta_1 = \upsilon_{23}\sin\theta_3 + s_3\omega_3\cos\theta_3 \\ -l_1\omega_1\sin\theta_1 = \upsilon_{23}\cos\theta_3 - s_3\omega_3\sin\theta_3 \end{cases} \qquad (8)$$

$$\begin{cases} l_3\omega_3\cos\theta_3 + l_4\omega_4\cos\theta_4 = 0 \\ -l_3\omega_3\sin\theta_3 - l_4\omega_4\sin\theta_4 = v_E \end{cases} \qquad (9)$$

The equations (8), and (9) can be expressed with matrix,

$$\begin{bmatrix} \cos\theta_3 & -s_3\sin\theta_3 \\ \sin\theta_3 & s_3\cos\theta_3 \end{bmatrix}\begin{bmatrix} \upsilon_{23}/\omega_1 \\ \omega_3/\omega_1 \end{bmatrix} = \begin{bmatrix} -l_1\sin\theta_1 \\ l_1\cos\theta_1 \end{bmatrix} \qquad (10)$$

$$\begin{bmatrix} 1 & l_4\sin\theta_4 \\ 0 & -l_4\cos\theta_4 \end{bmatrix}\begin{bmatrix} \upsilon_E/\omega_3 \\ \omega_4/\omega_3 \end{bmatrix} = \begin{bmatrix} -l_3\sin\theta_3 \\ l_3\cos\theta_3 \end{bmatrix} \qquad (11)$$

The system of equations (10) and (11) are the velocity ratio equations which can be solved with Matlab.

5. SOLUTION OF THE EQUIVALENT MOMENT OF INERTIA

Through above calculation, all unknown variables of the equivalent moment of inertia of six-rod mechanism of shaper have been completely solved out. Therefore, we can obtain the equivalent moment of inertia corresponding to the rotational angle of equivalent component. While the movement simulation is carried out with Matlab, the process to obtain those variables—position and velocity ratio, is programmed into an m-file, which can be invoked to solve the equivalent components at any rotational angle.

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According to the formula (1), the expressions of the equivalent moment of inertia of six-bar mechanism of shaper can be expressed as,

$$J_e = J_{s1} + J_{p1} + J_{m2} + m_3(\frac{\upsilon_{s3}}{\omega_1})^2 + m_4(\frac{\upsilon_{s4}}{\omega_1})^2 + m_5(\frac{\upsilon_{s5}}{\omega_1})^2 + J_{s3}(\frac{\omega_3}{\omega_1})^2 + J_{s4}(\frac{\omega_4}{\omega_1})^2 \quad (12)$$

Let $\varphi_0 = 0^\circ$, φ_i is gradually increased with step length 15°. The change curve of equivalent moment of inertia of six-bar mechanism is shown in Fig.3.

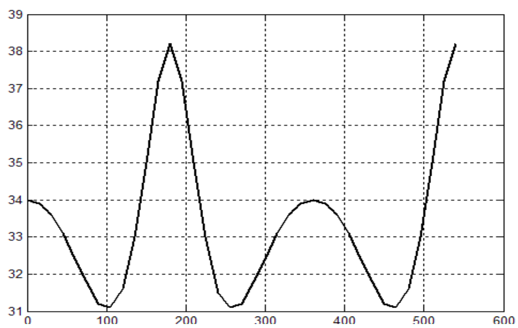

Fig.3 The Change Curve Of Equivalent Moment Of Inertia

As seen from Fig.3, the equivalent moment of inertia of the six-bar mechanism varies periodically with a period 360°, and is of symmetry relative to the middle position 180°. The maximum value 38（J/Kg • m2） occur at the position 180°, and the minimum 31（J/Kg • m2）at about 100° and 260°.

6. SOLUTION OF THE EQUIVALENT TORQUE

For the convenience of simulation and solution of the equivalent moment, some parameters about the mechanical system, such as mean rotational velocity ω_m of the driver, the power P of three-phase AC asynchronous motor and its mechanical properties g, must be given. Considering the mechanism that shown in Fig.1, the working resistance of plough head 5 is a function of position. Assuming the work done by the motor all evenly act on the six-bar mechanism, the mean resistance moment can be denoted as $M_m = P/\omega_m$.

Generally speaking, the mechanical property of three-phase ac asynchronous motor is a function of velocity. The mechanical property curve is shown in Fig.4. The BC segment which is the working section, is usually approximated with a line-segment from N to C point. The torque at N, M_n, is the rated torque of motor, and its rotational velocity ω_n is the rated rotational velocity of motor. The rotational velocity at C, ω_0, is the synchronous velocity of motor and the torque at C is zero. The driving torque at any point, M_d, is,

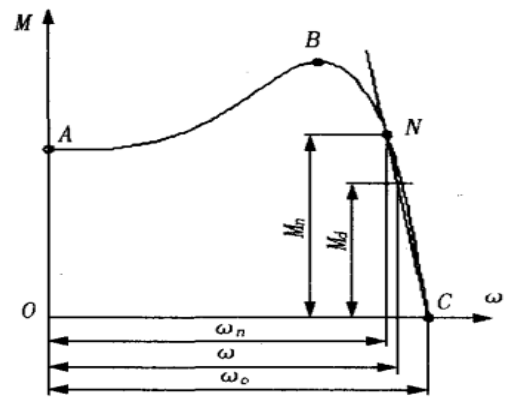

Fig.4 The Mechanical Characteristic Curve

$$M_d = \frac{\omega_m - \omega}{(\omega_0 - \omega_n)/M_n} + M_m \quad (13)$$

Here, $(\omega_0 - \omega_n)/M_n$ is the motor mechanical property coefficient g. So, formulae (13) can rewritten as

$$M_d = \frac{\omega_m - \omega}{g} + M_m \quad (14)$$

If the motor torque directly acts on the crank, the equivalent moment is,

$$M_e = M_d - M_m = (\omega_m - \omega)/g \quad (15)$$

So the equivalent moment is a function of velocity. The change curve of equivalent moment of six-bar mechanism for one cycle is shown in Fig.5. This curve is calculated and depicted with Matlab.

As seen from Fig.5, the equivalent moment of six-bar mechanism does not change periodically in the early stage. It illustrates periodicity after the

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crank turns to 105° where the system runs in a stable state.

7. MOVEMENT SIMULATION AND ANALYSIS

Set the initial conditions as ω_0 = 5 rad/s, t_0 = 0, ϕ_0 = 0, the calculated results are saved as an array. Using Matlab software to carry out the movement simulation, angular velocity and angular acceleration curve is shown in Fig.6.

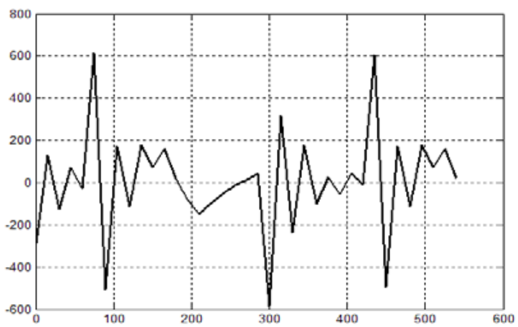
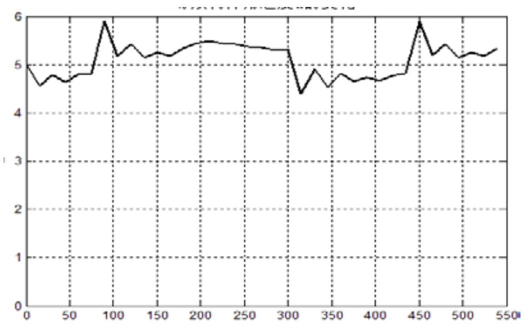
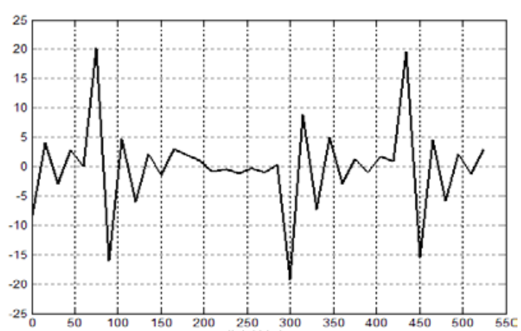


Fig.5 The Change Curve Of Equivalent Moment



(a) The angular velocity curve



(b) The angular acceleration curve

Fig.6 The Real Movement Of Shaper In The Stable Running Stage

As seen from Fig.6, the equivalent component of mechanism doesn't run with constant velocity in the running process, whereas the velocity in the stable running stage demonstrates the periodicity. When the equivalent component rotates within $60^\circ \sim 100^\circ$, the fluctuation is significantly larger. Because this range is just the quick return phase of six-bar mechanism of shaper, it is most likely to produce a velocity fluctuation. Simulation curve is consistent with the facts. As with Fig.5, at the given initial conditions, only when the equivalent component turns to 105°, does the system run in a stable state. The similar regularity illustrates that the velocity and acceleration of equivalent component have necessary relation with the rotational moment.

8. ADJUSTMENT TO FLUCTUATION

When the equivalent driving torque M_{ed} and equivalent impedance torque M_{er} of a mechanical system are equal, the machine will keep constant stable operation. Otherwise, if the driving power and impedance power are not equal at an instant, the surplus power or loss power will be produced, and it makes the velocity of the machine to increase or decrease, and lead to the velocity fluctuation. For the periodic velocity fluctuation, the approach to reduce angular acceleration of the equivalent component is to increase the quality or moment of inertia of equivalent component. The usual method is to install flywheel which can storage or release energy. For six-bar mechanism of shaper, if the variables of the equivalent moment of inertia be ignored, the rotational inertia of the flywheel mounted on the equivalent component can be determined with the formula below,

$$J_F = \frac{\Delta W_{\max}}{\omega_m^2[\delta]} - J_e \qquad (16)$$

Here, $\Delta W_{\max}$ is the maximum surplus-or-loss power of mechanical system. $\Delta W_{\max} = E_{\max} - E_{\min}$, $E_{\max}$ and $E_{\min}$ respectively denote the maxium and minium energy of the mechanical system.

If $J_e << J_F$, J_e can be ignored, then

$$J_F = \frac{\Delta W_{\max}}{\omega_m^2[\delta]} \qquad (17)$$

By calculation, we mount a flywheel which $J_e =$ 587.92849 （J/Kg • m2） on the rotary shaft

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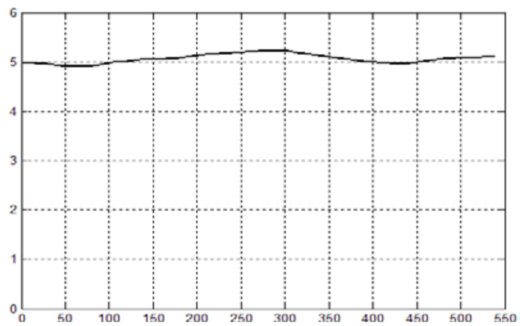
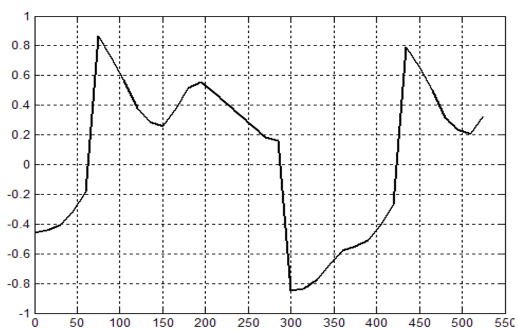
of the equivalent component. The curve of angular velocity and angular acceleration of the equivalent component are obtained after simulation with Matlab (Fig.7).



(a) The Angular Velocity Curve



(b) The Angular Acceleration Curve

Fig.7 The Real Movement Of Shaper Installing Flywheel

To compare Fig.7 with Fig.6, the curve of angular velocity and angular acceleration become smooth significantly after flywheel installation and their variation ranges reduce greatly. Their peak values are decreased by 11.3% and 99.57% respectively. It fully proves that flywheel is important to improve the movement stability of mechanism.

9. CONCLUSION

The kinematical and dynamical characteristics of six-bar mechanism of shaper are analyzed based on the closed vector loop equation, and simulation is carried out with Matlab. The simulation results reveal the real movement regularity of six-bar mechanism of shaper in the stable operation stage. According to the simulation results, a certain degree of velocity fluctuation exists in the running process inevitably. One of the main measures to reduce the velocity fluctuation is to install flywheel. The simulation results after installing flywheel show that the movement stability has been significantly improved. This method can be widely used to analyze the kinematical and dynamical characteristics of a known mechanism and improve its structure, or through the continuous simulation to seek optimal flywheel inertia for the mechanism.

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