Analysis of Modeling and Vibration Performance of a New Type of Cropping Machine

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Abstract: In order to reduce the cropping force and enhance the cropping cross-section quality, a new type of cropping machine is proposed in this paper. The basic structure and working principle of the cropping machine are introduced. Based on D’Alembert’s principle, the vibration equations of the cropping machine along the Y direction, X direction and around X, Y, Z axis are built in detail and the motion curves of vibration body in all directions are also obtained. The amplitude frequency response characteristic curve of the vibration body in Y direction is given and the resonance angular frequency of vibration body in Y direction is about 7.94 rad/s. The cropping experimental results show that the cropping force acted on the metal bar is low and the cross-section quality is very high.

Keywords: Amplitude frequency response, excited frequency, precision cropping, vibration mechanism.

1. INTRODUCTION

Cropping is often the first step of forging industry, and is also a key working procedure of producing the parts, such as standard pin, chain connecting pin, bearing roller and so on [1-3]. Nowadays, according to the metal bar, the cropping methods widely used are mainly punch shearing, saw cutting blanking lathe cutting. However, in these common cropping methods, some problems, which mainly include high stress, high energy consumption, poor cross-section quality, serious waste of raw materials as well as low production efficiency, often exist in industrial practice [4-7]. Therefore, a new type of cropping method is proposed in this paper. In the cropping process, V-shaped grooves are cut at specific length intervals in metal bar to engender the stress concentration at the bottom of the V-shaped groove. Then the slotted bar is fed to crop under the action of continuous symmetrical bending fatigue force and would rupture after certain periods. The structure of the new type of cropping machine is designed and its vibration performance is also analyzed in detail. The cropping experiments for 45 steel bars and 20 steel bars are carried out by means of the cropping machine.

2. THE BASIC STRUCTURE AND WORKING PRINCIPLE OF THE CROPPING MACHINE

The new type of cropping machine mainly consists of the electric machine, the eccentric block and the vibration body as shown in Fig. (1). The structure of eccentric block is shown in Fig. (2). The vibration body mainly includes the bed plate, the kinetic die, the vibration spring, the kinetic pressure ring. When the cropping machine works, the electric machine drives the eccentric block to rotate, which produces an uninterrupted exciting force. The exciting force will act on the metal bar circularly. Then the crack at the tip of V-shaped groove bottom expands slowly and regularly and finally the metal bar would rupture after certain periods.

Fig. (1). The basic structure of the cropping machine.
In order to sustain the vibration, there are 8 springs to support the vibration table.

![Diagram](image)

**Fig. (2).** The eccentric block.

### 3. THE VIBRATION PERFORMANCE ANALYSIS OF THE CROPPING MACHINE

#### 3.1. The Vibration Performance of the Cropping Machine

As is shown in Fig. (1), the vibration cropping mechanism proposed in this paper is a kind of single axis inertia vibration machine. The exciting force caused by two eccentric blocks does not pass through the center of mass of the vibration body, thus the vibration body will vibrate around its centroid. Based on the basic structure as shown in Fig. (1), the vibration mechanics model of the cropping machine is shown in Fig. (3). There are 5 freedoms in the vibration cropping mechanism.

Supposing that the total mass supported by the springs is the mass m, and m does not include the mass of two eccentric blocks. According to D’Alembert’s principle [8], the forces acted on the vibration body, which are inertia force, damping force, elastic force, exciting force and torque caused by exciting force should be balanceable and their resultant force is zero. Based on it, the vibration equations of the vibration body along the X direction, Y direction and around Z axis are given by

\[
\begin{align*}
\dot{y} &= \omega^2 y + \dot{x} = 2m_o \omega^3 r \sin \omega t \\
\dot{x} &= 2m_o \omega^3 r \cos \omega t \\
\dot{\phi}_y &= m_o \omega^2 r (L_{e1} - L_{e2}) \cos \omega t \\
\dot{\phi}_x &= m_o \omega^2 r (L_{e1} - L_{e2}) \sin \omega t \\
\dot{\phi}_z &= 2m_o \omega^2 r L_{e3} \cos \omega t
\end{align*}
\]  

(1)

where \( J_x, J_y, J_z \) are the moments of inertia of the vibration body along X axis, Y axis and Z axis respectively; \( J_{e1}, J_{e2}, J_{e3} \) are the moments of inertia of eccentric block around X axis, Y axis and Z axis respectively; \( L_{e1}, L_{e2}, L_{e3} \) are the distances between the force points of two eccentric blocks and the center of mass of the vibration body along Z direction respectively; \( L_{e0} \) is the distance between the gyration center of two eccentric blocks and center of mass of vibration body along Z direction; \( m_o \) is the mass of eccentric block; \( w, r \) are the angular velocity of electric machine shaft and the eccentric distance of eccentric block respectively; \( x, y, \phi \) are the accelerated velocities of vibration body in X direction and Y direction respectively; \( \dot{\phi}_x, \dot{\phi}_y, \dot{\phi}_z \) are the angular accelerations of vibration body around the X axis, Y axis and Z axis.

The special solutions of differential Eq. (1) are expressed as

\[
\begin{align*}
y_e &= \lambda_y \sin \omega t \\
x_e &= \lambda_x \cos \omega t \\
\phi_e &= \lambda_\phi \sin \omega t \\
\phi_\phi &= \lambda_\phi \cos \omega t
\end{align*}
\]

(2)

where \( \lambda_y, \lambda_x \) are the amplitudes of vibration caused by excited force in X direction and Y direction respectively; \( \lambda_\phi, \lambda_\phi, \lambda_\phi \) are the arguments caused by excited moments in X direction, Y direction and Z direction respectively.

Solving two order differential Eq. (2) and substituting the obtained results into the Eq. (1), the corresponding amplitudes of vibration and arguments in the Eq. (2) can be obtained as

\[
\begin{align*}
\lambda_y &= -\frac{2m_r \omega^3}{k - \omega^2 (m + m_o)} \\
\lambda_x &= -\frac{2m_r}{m + m_o} \\
\lambda_\phi &= -\frac{m_r (L_{e1} - L_{e2})}{J_1 + J_x} \\
\lambda_\phi &= -\frac{m_r (L_{e1} - L_{e2})}{J_2 + J_y} \\
\lambda_\phi &= -\frac{m_r L_{e3}}{J_3 + J_z}
\end{align*}
\]

(3)

Therefore, the equations of motion of any point in the vibration body can be written as

\[
\begin{align*}
y_e &= y_0 - \phi_e L_{e2} - \phi_e L_{e3} \\
x_e &= x_0 + \phi_e L_{e2} - \phi_e L_{e3} \\
z_e &= \phi_e L_{e3} + \phi_e L_{e3}
\end{align*}
\]

(4)

When \( m_o=3.7kg, r=24.17mm, m=248.3kg, J_x=0.258kg.m^2, J_y=0.915kg.m^2, J_z=0.657kg.m^2, L_{e1}=268.5mm, L_{e2}=296.4mm, L_{e3}=177.0mm \), the motion curves of vibration body in all directions are shown in Fig. (4). As is shown in Fig. (4), displacements of the vibration body in the X direction and Y direction are basically the same. Therefore, the influence of spring rigidity on the response of the vibration mechanism in the X direction and Y direction is very little. However, the
rotations of the vibration body around each axis are very different. The angles of rotation around X axis and Y axis are very little, and their differences are also small. The angle of rotation around Z axis is about 5 times of that of rotation around X axis. Therefore, in the course of the low-stress precision cropping, some necessary measures should be taken to reduce the influence on the cross-section quality. For example, the reasonable clamping position of the metal bar is determined [9], and the structure of the eccentric block is changed into the adjustable eccentric block [10, 11] and the external force load mode is studied in detail [12].
3.2. The Amplitude Frequency Response Characteristic

As is shown in Eq. (3), there is an important relationship between the vibration amplitude of vibration body in Y direction and the excited frequency. Based on Eqs. (3)-(4), the amplitude frequency response characteristic curve of the vibration body in Y direction is shown in Fig. (5). As is shown in Fig. (5), the vibration body in Y direction has an obvious resonance region, and the resonance angular frequency is about 7.94 rad/s. The amplitude of vibration of vibration body within the existing angular frequency is increased significantly near the resonance region. Therefore, in order to ensure the stability and reliability of the cropping machine in the course of the precision cropping, the cropping machine should be avoided working at this frequency. The best way is to pass this resonance frequency when the cropping machine works.

4. THE EXPERIMENTAL RESULTS OF THE CROPPING MACHINE

When the diameter of the metal bar is 15mm, the radius at the V-shaped groove bottom on the bar surface is 0.2mm, the groove depth is 0.6mm, and the flare angle of V-shaped notch is 90\(^\circ\), the cropping experimental results for 45 steel bar and 20 steel bar are shown in Figs. (6, 7) respectively. As is shown in Figs. (6, 7), the fatigue crack propagation region on the bar cross-section accounted for a relatively large area, the transient fault area is very small and the cross-section is very smooth. The fatigue crack expands along the upper and lower direction of the bar cross-section of the V-shaped groove, which is mainly related with the force in Y direction acted on the bar. As is shown in Fig. (1), the force acted on the metal bar is mainly the component force in Y direction. In addition, the cropping time for every segment of 45 steel bar is about 18s and the cropping time for every segment of 20 steel bar is about 15s. It is also found in the cropping that the smaller the transient fault area is, the longer the cropping time is.

Fig. (5). The amplitude frequency response characteristic curve.

Fig. (6). The cross-section for 45 steel bar.

Fig. (7). The cross-section for 20 steel bar.

CONCLUSION

(1) Based on the effect of stress concentration and bending effect, a new type of cropping method is proposed in this paper. The new type of cropping machine mainly consists of the electric machine, the eccentric block and the vibration body.

(2) The displacements of the vibration body in the X direction and Y direction are very small, and the angle of rotation of the vibration body around Z axis is about 5 times of that of rotation around X axis or Y axis.

(3) The vibration cropping machine in Y direction has an obvious resonance region, and the resonance angular frequency is about 7.94 rad/s.

(4) The cropping experimental results show that the cross-sections for 45 steel bar and 20 steel bar are very smooth and the cropping force acted on the metal bar is also reduced obviously. The smaller the transient fault area is, the longer the cropping time is.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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