Analysis of Ultrasonic Vibration Belt Grinding Processing Method

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Abstract. The sand belt abrasive distribution is relatively uniform, the grinding property is good, it is not easy to burn the workpiece. The sand belt grinding process has great flexibility and adaptability, it can be used for grinding of inner and outer circles, plane and complex curved surfaces. Compared with the closed belt, the open belt is continuously feed slowly. During the grinding process, new abrasive grain continuously enters into the grinding area. The surface quality is good, and one workpiece can be processed in one installation, reducing the assembly error caused by replacing the belt and shortening the processing time. For ultrasonic assisted machining technology, the two-dimensional ultrasonic assisted grinding have better processing results in reducing the grinding heat, the wear of the abrasive tool and the grinding force. By referring to the above processing techniques, this paper proposes a two-dimensional ultrasonic vibration open belt grinding processing method.

1. Introduction
With the improvement of the performance requirements of parts and the development of mechanical design, optical design and processing capability, the surface of the part contains a large number of concave and convex structures and tends to be complicated. The materials used are difficult to process, and there is almost no effective treatment for such parts. The processing method, and the two-dimensional ultrasonic vibration open belt grinding method can solve this problem well. Therefore, it is of great significance for two-dimensional ultrasonic vibration open belt grinding. Separate two-dimensional ultrasonic vibration is selected according to the existing two-dimensional ultrasonic vibration defects, and the grinding path of the abrasive belt is analyzed and simulated. Analyze the material removal mechanism, select the ultrasonic vibration phase, and establish a material removal model according to each processing parameter.

2. Ultrasonic vibration Abrasive Belt Grinding Technology Principle
Based on the flow cell width size limitation, the radial-tangential vibration grinding method is selected, as shown in Figure 1:
The principle of two-dimensional ultrasonic elliptical vibrating belt grinding technology is shown in Figure 1. Using the open belt grinding technology, ultrasonic vibration is carried out in the vertical direction of the belt and the horizontal direction of the workpiece. The relative motion trajectories of the two can be the surface of the workpiece is combined into an ellipse in the grinding feed direction, and the belt is fed to form a spiral motion path on the surface of the workpiece. The significance of vibration between the abrasive belt and the workpiece is that the two-dimensional ultrasonic vibration of the abrasive belt easily causes the abrasive belt and the contact wheel to fall off; the two-dimensional ultrasonic vibration of the workpiece makes the workpiece clamping mechanism complicated and affects the ultrasonic vibration characteristics, even the mechanism. Resonance cannot be achieved; and the application of two-dimensional ultrasonic vibration to the same target easily affects the vibrations in the two directions, causing errors in vibration and affecting the machining effect.

2.1. Theoretical Calculation and Trajectory Simulation of Elliptical Vibration Trajectory
As shown in Figure 2, during normal belt grinding [48], the abrasive trajectory of the abrasive belt is as follows:

Figure 1. Principle of two-dimensional ultrasonic elliptical vibration belt grinding technology

Figure 2. Ordinary belt grinding abrasive movement track
The equation of the abrasive particle trajectory is:

\[
\begin{align*}
    x &= \frac{d}{2}\sin(\omega_i t) - v_c t \\
    y &= \frac{d}{2} - \frac{d}{2}\cos(\omega_i t)
\end{align*}
\]  

(1)

In the above equation, \(d\) is the diameter of the belt pulley, \(\omega_i\) is the angular velocity of the belt rotation, and \(v_c\) is the feed rate of the workpiece.

On the basis of the ordinary abrasive belt grinding process, the tangential and radial ultrasonic vibrations of the same frequency are applied to the workpiece and the abrasive belt respectively to form a two-dimensional ultrasonic vibration abrasive belt grinding. The equation of the movement of the abrasive particles relative to the workpiece is:

\[
\begin{align*}
    x &= \frac{d}{2}\sin(\omega_i t) + a \cos(2\pi f t) - v_c t \\
    y &= \frac{d}{2} - \frac{d}{2}\cos(\omega_i t) + b \cos(2\pi f t + \varphi)
\end{align*}
\]  

(2)

In the above equation, \(a\) is the long axis and \(b\) is the short axis of the ultrasonic vibration; \(f\) is ultrasonic vibration frequency; \(\varphi\) is ultrasonic vibration phase difference;

2.2. Elliptical Vibration Trajectory Simulation

Define rate ratio \(R_s : R_s = \frac{v_c}{2\pi af}\)

For different vibration phase differences and rate ratios, the abrasive particle trajectory is shown in Figure 3:

\[
\begin{align*}
    (a) \quad \varphi = 0^\circ & \quad (b) \quad \varphi = 15^\circ, \quad R_s \leq 1 & \quad (c) \quad \varphi = 30^\circ, \quad R_s \leq 1 \\
    (d) \quad \varphi = 60^\circ, \quad R_s \leq 1 & \quad (e) \quad \varphi = 90^\circ, \quad R_s \leq 1 & \quad (f) \quad \varphi = 90^\circ, \quad R_s \geq 1
\end{align*}
\]

**Figure 3.** Abrasive trajectories of different phase and rate ratios

After applying two-dimensional ultrasonic vibration, when the \(\varphi\) is 0°, the trajectory of the abrasive grain is wavy, indicating that the applied two-dimensional ultrasonic vibration cannot form an ellipse, as shown in figure 3(a); However, the too small phase difference will also cause the two-dimensional ultrasonic vibration to not form an ellipse, as shown in Figure 3(b); When rate ratio \(R_s \geq 1\), regardless of the phase angle difference, the abrasive particles will form a wave-shaped motion track, as shown in Figure 3(f); This is the motion trajectory that this article does not want to get. These three situations are not considered. In other cases, the abrasive particles form a spiral motion trajectory, from Figure 3(c), (d), (e), it can be seen that the abrasive particle path is similar to the two-dimensional ultrasonic vibration tool cutting path.
3. Establishment of an Abrasive Vibration Belt Grinding Material Removal Model

3.1. Material Removal Mechanism
In this paper, the research on the grinding technology of two-dimensional ultrasonic vibrating abrasive belt is carried out. The processing method is a processing technology combined with the open abrasive belt grinding method and the traditional ultrasonic processing method. During the processing, each ultrasonic vibration period is sand. There is a separation process between the abrasive particles and the workpiece, so that the grinding force can be reduced, and the grinding fluid enters the gap between the abrasive particles and the workpiece, which can reduce the grinding heat and reduce the wear of the abrasive belt. When the workpiece is continuously processed, the abrasive particle of the abrasive belt will wear and break, and eventually the grinding ability will be lost. Then the abrasive belt will rotate, and the abrasive belt which loses the wear ability will move away from the grinding zone, and the new abrasive belt will be removed. The abrasive particles enter the grinding zone and cycle back and forth. The processing method maintains the characteristics of high processing precision, small processing force, good surface roughness of the workpiece, and the advantages of abrasive belt grinding "universal" grinding [1].

3.2. Elliptical Vibration Phase Determination
The phase difference in the existing two-dimensional ultrasonic vibration grinding is generally $\pi/2$ [2]. Although it is pointed out that the forces and heat generated by cutting are minimal when the phase difference is $\pi/2$, there is a lack of theoretical research [3] [4] [5] [6]. For abrasive belt grinding, the removal of workpiece material is the effect of multiple abrasive grains on the workpiece, that is, multiple abrasive grains are used to cut the workpiece, so cutting and grinding are certain. Similarity, the two-dimensional ultrasonic elliptical vibration grinding will be discussed in the phase difference theory. The difference of the vibration phase difference can cause the elliptical shape to be inclined, that is, the trajectory of the abrasive grain is inclined, and the processing thickness of the abrasive grain to the workpiece is different, as shown in Figure 4, the trajectory shape corresponding to different phases, when the phase is $0^\circ$, the trajectory is an oblique line. It can be concluded regardless of the phase difference, the horizontal position corresponding to the leftmost point of the ellipse is $-bcos\phi$ (take the ellipse center as the coordinate origin). When the phase difference increases, and the ultrasonic vibration elliptical inclination decreases.

![Figure 4. Elliptical shape corresponding to different phases](image-url)
In Figure 5, the phase difference increases with the same rate ratio, the maximum grinding thickness of the abrasive grains decreases, and this situation increases with the rate ratio. More obvious, mainly because the lowest point of the abrasive grain trajectory tends to be more to be processed, and the grinding state is under-grinding. At each rate ratio, there is a maximum grinding thickness jump value of the abrasive grain, which indicates that the phase and velocity ratio at this point just causes the abrasive grain to reach a critical grinding state. In the case of a phase difference with a relatively small rate ratio, under a large phase difference, there is a phenomenon that the phase difference increases and the maximum grinding thickness of the abrasive grains hardly changes. Therefore, at the same rate ratio, the larger the phase difference is, the easier the abrasive grinding state is from the over-grinding state to the under-grinding state, which is more advantageous for the removal of the workpiece. Similarly, for the same phase difference, the larger the rate ratio, the larger the grinding thickness of the abrasive grains, the easier the abrasive grinding state is from the under-grinding state to the over-grinding state, which is more detrimental to the removal of the workpiece.

In summary, under the same ultrasonic amplitude, feed rate and grinding depth, Abrasive grain grinding minimum thickness when phase difference is π/2. Further, it is easier to make the workpiece material in the plastic removal stage, and the abrasive-work contact rate is the largest, and the workpiece removal efficiency is high. Therefore phase difference is π/2 selected in this paper.

4. Conclusion
For the existing two-dimensional ultrasonic vibration defects, the separation two-dimensional ultrasonic vibration is selected, and the technical principle is analyzed to analyze and simulate the grinding path of the abrasive belt. Analyze the material removal mechanism, select the ultrasonic vibration phase, it is most reasonable to obtain the phase difference is π/2 from the grinding state analysis.

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