Research on Plane Grinding under Combined Movement of X-Y Axis
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Abstract. There are many parameters which can influence plane grinding. It is a situation in high workload and poor realizability to find the optimization parameters of the grinding by using experimental method. Taking x-y linkage plane grinding as the platform, research on different influence of grinding quality with 4 factors including initial diameter of the abrasive, initial phase angle, lapping plate & workpiece speed ratio and x-y linkage workbench though simulation. The results show that initial radius vector of the abrasive basically has no effect on grinding trace. When speed ratio between lapping plate with workpiece is decimal the grinding trace seems much better. The significant influence of grinding quality can made by straight and helical x-y linkage motion on workbench.

Introduction
Grinding is an important precision, ultra-precision machining technology, almost suitable for a variety of materials processing. At present in our apparatus, machine tools, aviation and power machinery industries, grinding is in a very wide range use from manufacturing, assembly and maintenance work. Grinding process can make very high surface accuracy, while the grinding device is relatively simple. In a grinding process, the relative motion between the workpiece and the lapping, has a direct impact on the quality and efficiency of the workpiece, so as on the promotion of nano-processing technology applications.

At present, there are few new grinding methods in China. grinding methods such as linear grinding, rocking grinding and planetary grinding are based on the traditional biaxial grinding method, by adding or changing the grinding mechanism to synthesize new grinding tracks, improve the workpiece center grinding traces of poor variability uneven grinding quality and other issues [1-3]. But the key problem is that the increased motion law can only make the distance between the workpiece and the lap center to obtain periodic changes, the grinding center of the workpiece trajectory is still a recurring defect which can not fundamentally eliminate the problem of poor time variability. At the same time, increasing the grinding movement means grinding mechanism is more complex, so that manufacturing and processing costs rise.

In this paper, a multi-parameter planar fixed abrasive grinding machine as the research platform (see Figure 1), mainly research what can affect the quality of the workpiece surface grinding and analysis grinding track ,then simulate the response.

Multi-Parameter Plane Grinding Processing Theory
Aiming at the above problems, this paper presents a multi-parameter planar grinding method using the fixed abrasive grinding technology. Except the rotation movement between workpiece and grinding disc, there are X and Y axis of the linkage movement, the location of workpiece and grinding disc changes after linkage movement in the real-time. The grinding method can realize fixed and variable eccentric abrasive. When the X and Y axes are linked, any point on the workpiece surface will have a time-varying grinding track, not only the track repetition rate will be low, but also get a more uniform distribution speed. From the grinding theory, it is overcome the shortcomings of planetary grinding method, and conducive to better and more uniform surface quality of processing.
Multi-parameter planar grinding mechanism as shown in Fig. 1, the main movement of grinding is provided by the rotary motion of grinding disc and magnetic table, and the Z-axis motor drives the grinding disc to realize the Z-direction feed movement to provide the grinding pressure for the grinding process. The workpiece is fixed on the magnetic table fixture, led the workpiece to do rotary motion, the position of the fixture can be adjusted, thereby changing the eccentricity of the workpiece relative to the grinding disc. In addition to rotary motion of grinding disc and magnetic table, grinding machine in X, Y have two degrees of freedom respectively, with the workpiece in the X, Y and under the role of rotary motion in the grinding process, the workpiece can reach all positions of the grinding disc.

By setting the grinding parameters, the time-variation of the grinding process is greatly enhanced, and the precision of the grinding process can be improved. At the same time because the workpiece can reach almost all the location on the grinding disc, the workpiece on the grinding disc wear more uniform, reducing the number of grinding, thereby improving the efficiency of the grinding disc. The combined movement of X, Y-axis is introduced to make the trajectory more complex. In the processing there are a number of process parameters, so this processing method named multi-parameter grinding method.

Analysis of the Relative Motion between Workpiece and Grinding Disc

The relative movement between the grinding disc and the magnetic chuck is composed of the rotary motion of the grinding disc and the workpiece and the combined motion of the X and Y axes. The principle of plane grinding is shown in Fig.2. Let \( \Sigma O \) be the machine coordinate system \( XOY \); \( \Sigma O_1 \) be sucker coordinate system \( X_1O_1Y_1 \), the origin is the suction cup center; \( \Sigma O_2 \) be grinding disc coordinate system \( X_2O_2Y_2 \), the origin is the center of the grinding disc; \( \Sigma O_3 \) be workpiece coordinate system \( X_3O_3Y_3 \), the origin is the center of the workpiece.

Initial position \( OX \), \( O_2X_2 \), \( O_3X_3 \) are in the direction of the \( OO_2 \) connection, \( O \), \( O_2 \), \( O_3 \) are the origin respectively. Let the counterclockwise direction be positive, the radius of the chuck is \( r_1 \), and the angular velocity is \( \omega_1 \); the radius of the grinding disc is \( r_2 \), and the angular velocity is \( \omega_2 \). The chuck moves in the right direction in the Y direction with an initial offset of \( e_1 \). The grinding disc is translated in the X direction to the right, with an initial offset of \( e_2 \). The distance on the grinding disc between any point on \( m \) and \( O_2 \) is \( R_m \), the initial phase angle is \( \theta \). After processing \( t \), the suction cup turns over the angle \( \theta_1 \), the grinding disc turns over the angle \( \theta_2 \). X-axis movement speed is \( V_x \) (mm/s), Y-axis movement speed is \( V_y \) (mm/s). The radius of the circle when X and Y are linked is a(mm).
According to the principle of D-H method, the coordinate transformation matrix between $\Sigma O_3$ and $\Sigma O_1$ can be written as:

\[
\begin{bmatrix}
\alpha_{T_{O_1}} \\
\end{bmatrix} = \begin{bmatrix}
\cos(\omega_1 t) & -\sin(\omega_1 t) & 0 & r_1 \cos(\omega_1 t) \\
\sin(\omega_1 t) & \cos(\omega_1 t) & 0 & r_1 \sin(\omega_1 t) \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}^{-1}
\]

(1)

the coordinate transformation matrix $\alpha_{T_{O_2}}$ between $\Sigma O_1$ and $\Sigma O_2$ can be written as:

\[
\begin{bmatrix}
\alpha_{T_{O_2}} \\
\end{bmatrix} = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & Y \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}^{-1} \begin{bmatrix}
1 & 0 & 0 & X \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}
\]

(2)

Then the final transformation matrix between the workpiece coordinate system $\Sigma O_3$ and the grinding disk coordinate system $\Sigma O_2$ is

\[
\begin{bmatrix}
\alpha_{T_{O_3}} \\
\end{bmatrix} = \begin{bmatrix}
\alpha_{T_{O_1}} \\
\end{bmatrix} \begin{bmatrix}
\alpha_{T_{O_2}} \\
\end{bmatrix} = \begin{bmatrix}
\alpha_{T_{O_1}} \\
\end{bmatrix}^{-1} \begin{bmatrix}
\alpha_{T_{O_2}} \\
\end{bmatrix}^{-1} \begin{bmatrix}
\alpha_{T_{O_3}} \\
\end{bmatrix}
\]

(3)

The coordinate matrix of $\Sigma O_3$ for any point M on the grinding disc is

\[
\begin{bmatrix}
\alpha_{M} \\
\end{bmatrix} = \begin{bmatrix}
R_m \cos(\omega_2 t) \\
R_m \sin(\omega_2 t) \\
0 \\
1 \\
\end{bmatrix}
\]

(4)

The trajectory of point M on the workpiece is the coordinate of point M in $\Sigma O_3$

\[
\begin{bmatrix}
\alpha_{X_m} \\
\alpha_{Y_m} \\
\alpha_{Z_m} \\
1 \\
\end{bmatrix} = \begin{bmatrix}
R_m \cos(\omega_2 t - \omega_1 t - \theta) + X \cos(\omega_1 t + \theta) - Y \sin(\omega_1 t + \theta) - r \\
R_m \sin(\omega_2 t - \omega_1 t - \theta) - X \sin(\omega_1 t + \theta) - Y \cos(\omega_1 t + \theta) \\
0 \\
1 \\
\end{bmatrix}
\]

(5)
By D-H method to conclude one point on plane grinding disk across the workpiece track curve formula
\[
\begin{align*}
\dot{X}_m &= R_m \cos(\omega_2 t - \omega_1 t - \theta) + X \cos(\omega_1 t + \theta) - Y \sin(\omega_1 t + \theta) - r \\
\dot{Y}_m &= R_m \sin(\omega_2 t - \omega_1 t - \theta) - X \sin(\omega_1 t + \theta) - Y \cos(\omega_1 t + \theta)
\end{align*}
\] (6)

Where
\[
\begin{align*}
X &= (e_2 + V_x t) + a \cos(\omega_3 + \theta_1) \\
Y &= (e_1 + V_y t) + a \sin(\omega_3 + \theta_1)
\end{align*}
\] (7)

\(\omega_1\) is X, Y do circular track linkage angular velocity, a is the radius of the circle, \(\theta_1\) is the initial phase

\[
V_x = \begin{cases} 
1 \text{mm/s} & \text{t/120 Be even} \\
-1 \text{mm/s} & \text{t/120 Be odd}
\end{cases}
V_y = \begin{cases} 
1 \text{mm/s} & \text{t/120 Be even} \\
-1 \text{mm/s} & \text{t/120 Be odd}
\end{cases}
\]

According to the above analysis, Matlab is used to simulate the trajectory of abrasive grain. The simulation process is shown in Figure 3.

Grinding Trajectory Simulation Analysis

The parameters that affect the grinding trace are as follows \(\omega_1\), \(\omega_2\), \(R_m\), \(\theta\), \(e_1\), \(e_2\), \(V_x\), \(V_y\), \(\omega_3\), a. When the X, Y linkage to go back and forth spiral, and the spiral line each time there is a certain deviation, so that the track repeat time is greatly extended, combined with other parameters of a variety of combinations, the workpiece surface to obtain uniform, no direction of the grinding direction of the track. The influence of multi - parameters on the grinding trajectory is studied by using matlab as simulation tool.

The Influence of Initial Point Diameter on the Grinding Trajectory Curve

The influence of different diameters \(R_m\) on the trajectory of abrasive grains was analyzed. Take \(\theta = 0\), X, Y do spiral movement, \(V_x = 1 \text{mm/s}\), \(V_y = 0 \text{mm/s}\), a=60mm, \(e_2 = 40\) mm, \(\omega_1\) take 33r/min,
43r/min respectively. \( \omega_2 \) take 35r/min, 45r/min respectively. \( R_m \) take 70, 100, 140, respectively. The results shown in Figure 4.

Figure 4. Diameter to the initial point on grinding track (\( \omega_1 = 33r / \min, \omega_2 = -35r / \min \)).

Figure 5. Diameter to the initial point on grinding track (\( \omega_1 = 33r / \min, \omega_2 = 45r / \min \)).

Figure 6. Diameter to the initial point on grinding track (\( \omega_1 = 43r / \min, \omega_2 = -35r / \min \)).

Figure 7. Diameter to the initial point on grinding track (\( \omega_1 = 43r / \min, \omega_2 = -35r / \min \)).
From Fig. 4 to Fig. 7, it can be seen that, for different values $\omega_1$, $\omega_2$, the trajectories of abrasive grains follow the same law, that is, with the $R_m$ increase, the trajectory of the abrasive grains deviates from the center of the workpiece. The general shape of the track does not change. That is, the position of the abrasive grains at the initial time is far away from the center of the grinding disc, the grinding movement trajectory passes through the larger range, the initial time the position of the abrasive grains closer to the center of the grinding disc, grinding movement trajectory range is smaller; With the increase of $R_m$, the trajectory curve coverage area increases. The size of the value $R_m$ determined by the size of grinding.

**Effect of Initial Phase Angle of Grinding Trajectory Curve**

Figure 8 for the initial phase angle $\theta$ of 0° and 90° respectively, the grinding trajectory curve. The two track curves are rotated only 90° along the center of the workpiece. It can be seen that the value of the initial phase angle only affects the phase of the grinding trajectory curve and does not affect the shape and amplitude of the trajectory and has no effect on the grinding quality.

![Figure 8](image)

**Influence of Speed Ratio on Grinding Trajectory Curve**

Take $r=0$, $R_m=70$mm, $\theta=0^\circ$, X, Y linkage, the rotation speed ratio $n$ is the rotation speed of the grinding wheel to the speed of the upper workpiece. Now take two sets of the same speed, but the speed of different circumstances to test. Take $\omega_1=25$ r/min, $\omega_2=45$ r/min and $\omega_1=50$ rad/s, $\omega_2=90$ rad/s, 2 sets of speed in the same time simulation.

![Figure 9](image)

When the rotational speed $\omega_1$ or $\omega_2$ at the time of X and Y linkage has no common divisor with respect to $\omega_3$, the shape of the grinding locus curve is basically the same, and with common ratio but
the angular velocities of Fig. 9 (a) and (b) are different. The simulation results show that the trajectories of group (b) are more dense than those of group (a), but the track shape and distribution are basically the same. Can regard two rotational speed as an influence parameter—rotational speed n. The speed ratio is the same, the change of grinding track curve is basically the same, in the same time, the higher the speed, the greater the density of the track in the same time. So improving the grinding speed is conducive to the improvement of grinding efficiency. Keep the other simulation parameters unchanged, take \( \omega_1 , \omega_2 \) different values respectively, the simulation results to obtain different graphics.

Figure 10. Grinding trajectory curves in different speed ratio.

Figure 10 for the different speed ratio of grinding trajectory curve, speed ratio n = 2,3,4, -2, -3, -4,0.8,1.3,1.157, -0.8, -1.3, -1.157. It can be seen that the speed ratio has a significant impact on the
abrasive particle trajectory. When the speed ratio is integer, the trajectory of abrasive grain has a strong regularity. The trajectory of abrasive grain appears petaloid line. The speed ratio is related to the number of petals, and the direction of speed ratio has a certain relation with the petal shape. When the speed ratio is decimals, the movement trajectory of the abrasive grains is more chaotic and the distribution is more uniform. When the speed ratio is irrational, the trajectory of the abrasive grains covers more evenly.

When the positive speed ratio, the trajectory of the abrasive grain is epicycloid, the curvature of the trajectory curve is more uniform and suitable for lapping; Negative speed ratio, the trajectory is the cycloid, curve curvature, speed changes, is not conducive to the quality of the surface of the workpiece.

**XY linkage on the grinding trajectory curve**

In the multi-parameter grinding method, X, Y linkage mode is also to change the grinding grain trajectory process parameters, when X, Y do not do any movement with the traditional eccentric grinding the same, but when using different linkage motion trajectory, inevitable in the workpiece surface have different grinding processing trajectory curve. Figure 11 shows the simulation results when the other simulation parameters are unchanged and X and Y are in different linkage modes.

![Simulation results](image)

Figure 11. The trajectory with X, Y different linkage ways.

Fig.11 Simulation results show that the trajectories are unevenly distributed on the workpiece and the curvature of the trajectory changes greatly when the X and Y are linked in a straight line. When the linkage way to go round, the larger the circle is, the more uniform the distribution and curvature of the trajectory are. When the circle exceeds a certain limit, the disc will run out of the workpiece range. It is not conducive to the uniformity of grinding. When the linkage method for the spiral, greatly extending the grinding cycle, in theory, can achieve the grinding movement trajectory does not repeat. At the same time, the initial offset and the speed of linkage also have a certain impact on the trajectory.
Conclusion
In this paper, X-Y linkage planar grinding is taken as the research object. Research on different influence of grinding quality with 4 factors including initial diameter of the abrasive, initial phase angle, lapping plate & workpiece speed ratio and x-y linkage workbench though simulation. Then the simulation results are analyzed. The results shows that:

(1) The initial point to the diameter of the grinding track does not have an impact.

(2) When the speed ratio is positive, the trajectory of the abrasive grain is epicycloid, the curvature of the trajectory is more uniform, and it is suitable for the lapping process. The speed ratio of the abrasive grains is Negative number, the trajectory is the internal cycloid, the curvature of the curve is large, the speed of change is large, so negative speed is conducive to the improvement of grinding efficiency, suitable for rough research.

(3) When the work table by X-Y linkage to go straight, the track is unevenly distributed on the workpiece; circular linkage when the circular approach to the larger circular radius, track distribution and curvature changes more uniform; When the spiral line, can greatly extend the grinding cycle, in theory, can achieve the grinding movement trajectory does not repeat, so that any point on the workpiece trajectory does not appear periodic repetition.

References


