Analysis of Z-axis Rigid of PCB CNC Drilling Machines

Liang-jin Cai*, Chang-tao Cai†, Fei-Da Mac
Mechanical Engineering and Automation of Xihua University, Sichuan Chengdu 610039, China
*corresponding author, e-mail: 127clj@163.com*, cct0622@mail.xhu.edu.cn†

Abstract
This article for the printed circuit board (PCB) CNC drilling machine dynamic character and rigidity analysis of Z-axis, With ADAMS motion simulation of the Z-axis program, come to the bit offset of the rig during the drilling process in the X-axis and Y-axis direction, and then use the quadratic elements of the completed prototype data test, the measured data and simulation data compare validation to identify the impact of the motion parameters of accuracy of ultra-high-speed electric spindle drilling. Using ANSYS on the overall structure (in particular, the structure of Z-axis) to optimize the structure analysis, the optimal structural parameters. This article both specific theoretical analysis, but also the experimental verification, through theoretical analysis and experimental validation of the Z-axis structure play an important role to improve the ultra-high-speed electric spindle dynamic accuracy and rigidity in the drilling process.

Keywords: rigid analysis, motion simulation, ultra-high-speed electric spindle, structural optimization, dynamic performance

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1. Introduction
With the rapid development of industrialization, automation and information technology, high reliability requirements of the multi-functional, lightweight, miniaturization of electronic products, making the PCB to the high-density, high integration and miniaturization, multilayer and special functional direction rapidly. Therefore, the mechanical dynamic characteristics of the PCB CNC drilling machines in the high-speed state and rigid control, as the development of high-speed (300Krpm above) and precision (within ± 0.002mm) important part of the PCB CNC drilling machine. At this stage the majority of PCB CNC rigs drilling frequency is still very low, most of the rigs drilling a frequency of about 400/min, however, a relatively high point of China - Han, Tian Ma rig drilling frequency can reach 500/min, Due to insufficient rigidity of the ultra-high-speed electric spindle drilling and the overall machine tool dynamic characteristics (especially the Z-axis dynamic characteristics) and other reasons, the domestic PCB CNC rigs drilling accuracy is relatively low, in the case of open fast drilling.

This paper studies the PCB CNC drilling machine is Pengzhou’s Da Li Precision Mechanism Ltd DLD26A PCB CNC drilling machine, currently the company's PCB CNC drilling machine has the problems of open fast drilling, dynamic characteristics of machine tool's difference and less rigid, causing the borehole accuracy is not high, the unreasonable structural design and machining technology of low level is the effect of the machine tool improving the performance of the key to factor.

2. Z axis Scheme
At present, the market for high integration, high-precision double-sided and multi-layer printed circuit board to demand more and more urgent, therefore, developed with independent intellectual property rights of the high precision, high performance PCB NC drilling machine is currently the primary task. The developed prototype quality reached the advanced level at home and abroad, some domestic and foreign leading PCB NC drilling machine some parameters as shown in Table 1.

As you can see from Table 1, the domestic PCB CNC drilling machine drilling range has reached the advanced level in foreign countries, but the precision of hole, positioning accuracy, repeatability are lagging behind the foreign drilling rig.

The PCB CNC drilling machine has three main Z axis research program.
(1) A linear bearing (rigid connection) a universal coupling (flexible connection) in Figure 1.
(2) Aerostatic bearing (flexible connection) Coupling (rigid connection) in Figure 2.
(3) Aerostatic bearing (flexible connection) a universal coupling (flexible connection) in Figure 3.

Table 1 PCB CNC drilling parameter table

<table>
<thead>
<tr>
<th>Name</th>
<th>Range of drilling mm</th>
<th>Z axis speed mm/min</th>
<th>Positioning precision mm</th>
<th>Repeat accuracy mm</th>
<th>Precision drilling mm</th>
<th>Spindle speed Kr/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>China-Han</td>
<td>0.1-6.35</td>
<td>30</td>
<td>±0.005</td>
<td>±0.0025</td>
<td>±0.0254</td>
<td>180/200</td>
</tr>
<tr>
<td>Japan-Hitachi</td>
<td>0.1-6.35</td>
<td>25.4</td>
<td>±0.004</td>
<td>±0.002</td>
<td>±0.015</td>
<td>160/200</td>
</tr>
<tr>
<td>Germany-SCHMOLL</td>
<td>0.1-6.35</td>
<td>25</td>
<td>±0.004</td>
<td>±0.002</td>
<td>±0.018</td>
<td>160/300</td>
</tr>
<tr>
<td>Switzerland-POSALUX</td>
<td>0.05-6.35</td>
<td>30</td>
<td>±0.004</td>
<td>±0.002</td>
<td>±0.018</td>
<td>180/300</td>
</tr>
<tr>
<td>USA-EXCELLON</td>
<td>0.1-6.35</td>
<td>38</td>
<td>±0.005</td>
<td>±0.0025</td>
<td>±0.018</td>
<td>180/200</td>
</tr>
</tbody>
</table>

Figure 1 Z-axis Option I  Figure 2 Z-axis Option II  Figure 3 Z-axis Option III

Figure 4 Workbench meshing  Figure 5 Z-axis aerostatic bearing meshing

Figure 6 Z axis universal coupling meshing  Figure 7 Machine stationary parts of the mesh
The first Z axis scheme adopts linear bearing and a universal joint. The advantage of linear bearings: (1) carrying the ball and spindle in point contact, the use of small load. (2) The ball with a minimum frictional resistance to rotation, thereby obtaining high precision and smooth motion. Disadvantages: The positioning performance is not good. Universal coupling plays a major role in regulating heart and self-aligning effect is good. The second Z axis scheme adopts aerostatic bearing (floating sleeve) and coupling, the advantage of aerostatic bearing: (1) the air static pressure bearing and spindle without contact, reducing the Z axis motion load. (2) the air static pressure bearing has a positioning guiding function. Coupling self-aligning effect is bad.

The third Z axis scheme adopts aerostatic bearing and universal joints. Using ANSYS on the PCB NC drilling machine of the whole structure by optimization of structure, obtain the optimal structure parameters, the following is part of the structure of the finite element mesh model.

3. Rigid analysis

The motion simulation is built by solving the nonlinear equations of the displacement and velocity to determine the displacement, velocity and time relationships, each of the above three structures do motion simulation, and X and Y of the PCB CNC machine tool feed direction of movement vibration components come to the vibration amplitude of the bit. The first drill vibration amplitude of the Z axis structure is as follows Figure 8 shows, the drill bit vibration amplitude of the second Z-axis structure is as follows Figure 9 shows the third Z-axis structure drill vibration amplitude as follows as shown in Figure 10.

![Figure 8](image1.png)
Figure 8 the first structural drill vibration curve

![Figure 9](image2.png)
Figure 9 the second structure drill vibration curve

![Figure 10](image3.png)
Figure 10 the third structural drill vibration curve

![Figure 11](image4.png)
Figure 11 the third structure optimized drill vibration curves

The third structure is the best of several options can be drawn from the drill bit vibration curve. Using ANSYS to optimize the structure of the third structure, and optimization of drill vibration amplitude shown in Figure 11. It can be seen from Figure 8 and Figure 10, the positioning of the guiding role of aerostatic bearing is better than linear bearings. Universal joint (flexible connection) than the coupling (rigid connection) more effective regulation of the dynamic performance of the ultra-high-speed electric spindle can be seen from Figure 9 and...
Figure 10. Studies have shown that the impact of high-precision and high-speed PCB CNC drilling mechanical vibration of the main factors: poor spindle dynamic characteristics, inappropriate parts of the rigidity, accuracy and rigidity of the poor-oriented institutions, sports and the static structure of the mass ratio of inappropriate and so on.

Secondary completion of the third program DLD26A prototype performance parameters were measured, and randomly select a spindle measurement data as the experimental data, the first spindle measurement data are shown in Figure 12.

Figure 12 the theoretical position of the hole and the actual position deviation

The following diagram 13 shows, the hole of theory and actual position deviation in the X-axis direction

Figure 13-hole theory and the actual location of the deviation in the X-axis direction

The following diagram 14 shows, the hole of theory and actual position deviation in the Y-axis direction

Figure 14-the hole theory and the actual location of the deviation in the Y-axis direction
Through theoretical and experimental data show that, to improve the PCB CNC drilling machine Z-axis rigid, aerostatic bearings and universal joints of the structure is the key factor. A marked improvement of the optimized PCB CNC drilling machine drill dynamic characteristics can be drawn from Figure 11. By adopting these measures, in the actual process can DLD26A type PCB CNC drilling machines to drill tiny holes range from the original \( \phi 0.3 \text{mm} \) to \( \phi 0.1 \text{mm} \), greatly improve the PCB CNC drilling machine Micro-hole Machining capacity.

4. Conclusion
The development objectives of the PCB CNC drilling machine is a high-precision and high speed conditions ultrafine pore and deep hole processing capacity, how the reasonable control of the motion characteristics of the PCB CNC drilling machines in the state of high-speed processing and component rigid is to achieve the key to this goal. Motion simulation can be an intuitive measure of the mechanical dynamic characteristics of the PCB CNC drilling machine, effective control of the mechanical dynamic characteristics of the PCB CNC drilling machine drilling capacity can significantly improve the state of high-speed machining.
Motion simulation analysis on the three programs, obtained using the aerostatic bearing (vibration-rotation accuracy, dynamic characteristics, etc.) and the universal joint program with the best dynamic performance. Practice has proved that the PCB CNC drilling machine speed electric spindle drilling process, the torque and rigidity of the two key factors that affect the quality of drilling and the application of the universal joint solution to these two factors significantly increase the fine holes drilling accuracy.

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References