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The feasibility study of using a kinematic for 6-degrees tool holder in single point diamond turning

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Abstract

Multi-axis micro-cutting machines with the parallel kinematic configuration are promising because it can reduce multiple cyclic repetitive alignment setups, and is able to adjust the pose of diamond tool during the turning process. In this paper, a micro-cutting centre is developed. The key component is the 6-axis tool holder which consists a Hexapod robot. One major problem of using the Hexapod robot to cut metals is that the its stiffness is much smaller than that of machine slides. The dynamic performances of Hexapod and machine slide are compared. It is found that although the Hexapod mechanisms induce new peaks in the PSD of thrust force, the amplitude of the vibration is insignificant in the thrust direction. Experimental results show that the surface roughness of the specimen machined by the proposed tool holder could attain the sub-micrometric level.

Keywords: ultraprecision, multi-axis, dynamics of hexapod

1. Introduction

Multi-axis micro-cutting machines with precision positioning capability and parallel kinematic configuration are regarded as the machine tools of next generation [1,2]. Since the load is shared by all the struts or legs, machines with parallel kinematic configuration are able to achieve better payload-to-weight ratio and more compact structures [2,3]. In addition, all the geometric errors of each axis in a parallel kinematic machine (PKM) are coupled and averaged to be a final volumetric error. Therefore, PKMs have potentials to achieve higher accuracy than that of serial kinematic machines (SKM). The PKMs with Stewart-Gough parallel kinematic architectures are defined as Hexapod, which has 6 degrees of freedom.

With the advances in optics, there has been a growing interest in the fabrication of discontinues freeform surfaces, such as microlens arrays (MLA) [4]. However, the F-number of our MLA cannot be reduced to be less than 4, because the orientation of the diamond tool cannot be adjusted during the cutting process, so that the interference will occur between the machined surface and flank face of the diamond tool. To solve the interference issue, a Hexapod (Hexapod h-811 from Physik Instrumente company) is modified as a tool holder, which provides the diamond tool with motion of 6 degrees of freedom. However, one problem emerges that although the cutting force is usually smaller than 0.1 N, the vibration between the diamond tool and the workpiece may occur due to the low stiffness of Hexapod (3 N/μm).

In this paper, a novel tool holder is developed by modifying a 6-axis Hexapod for the lathe. Experiments were conduct to study the feasibility of the tool holder in metal machining, special attention is focused on its dynamic performance.

2. Development of 6-axis tool holder

The proposed tool holder is assembled in a machine with a Hexapod mount and a T slot table. The whole machine layout also contains a spindle, a spindle mount and a lathe base as shown in Figure 1. Note that the longitudinal axis of the Hexapod is placed horizontally, because the stiffness and accuracy are higher in its longitudinal direction.

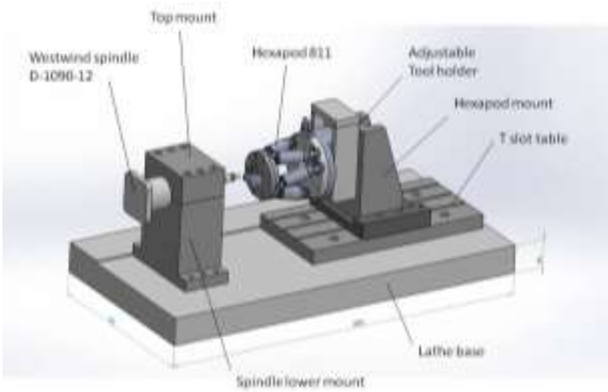
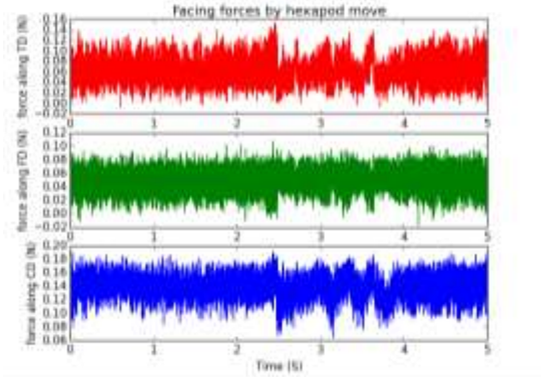


Figure 1. Layout of the micro-cutting machine

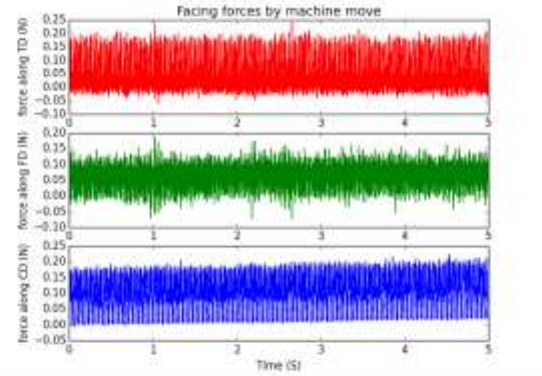
3. feasibility study of the tool holder

Two aluminum 6061 workpieces were faced by the diamond tool mounted on the center of moving platform of the tool holder. The first workpiece was machined by the movement of Hexapod struts without any motion of the machine tool slide, while the second workpiece was machined by movement of machine tool slide when the moving platform remained at the zero position in the Hexapod coordinate system. During the experiment, the spindle rotated at 1500 rpm, the feedrate at 1 mm/min, and the depth of cut at 2 μm. The cutting force in thrust direction (TD), feed direction (FD) and primary cutting direction(CD) were measured by a force sensor (Kistler 9251A).

Figure 2 shows the cutting forces along TD, FD and CD when facing by the movement of the Hexapod and by the movement of the machine slide, respectively. It can be seen that the amplitude of the cutting forces in relation to Hexapod movement varies more largely than that of cutting forces in relation to the machine slide movement. Which suggests that the stability of Hexapod is lower than that of machine slide in the cutting process.



(a)



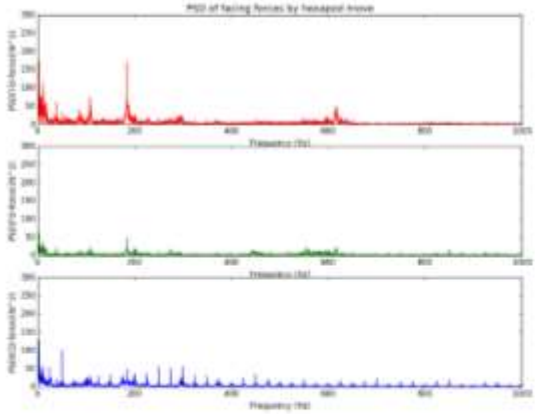
(b)

Figure 2. (a) Cutting forces in relation to by Hexapod move (b) Cutting forces facing by machine move

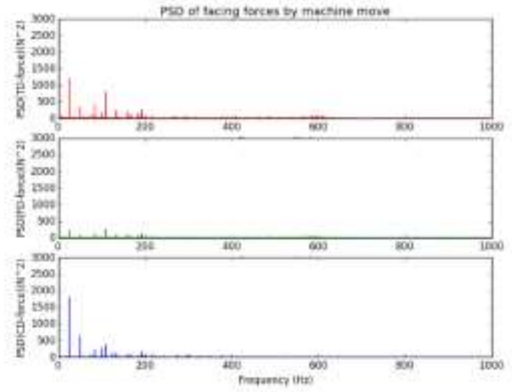
The power spectral density functions (PSD) of these forces (Figure 3) show that apart from the frequencies related to the spindle vibration, the unique frequencies (11.4Hz, 107.9Hz and 184.8Hz) are induced by the Hexapod mechanism. The data recorder of the Hexapod was used to record the position of the center of the moving platform, and the PSD of the position data was also obtained (Figure 4). The peaks in the TD almost disappear due to the higher stiffness in this direction. The peaks in the CD are noticeable at the frequencies of 25.4Hz, 37.7Hz, 50.6Hz, 130.4Hz and 184.8Hz. Compared with the force and position PSDs, although the peaks at 184.8 Hz in the PSD of the thrust forces in relation to Hexapod movement is prominent, the amplitude of the vibration at 184.8 Hz is not noticeable. This is the main reason that the Hexapod is assembled on the machine tool in the horizontal direction. The average surface roughness (R_a) corresponding to the Hexapod facing is 23.5 nm, which is larger than the average surface roughness (19.8 nm) corresponding to the machine facing. The surface roughness of the workpiece cutting by the Hexapod is slightly worse than that of cutting by the machine slide, because the tool path discrepancies are due to the non-linear kinematic movement of the Hexapod. However, if freeform surface machining is concerned, the discrepancies will be narrowed down to become insignificant, because all the geometric errors of each axis in a parallel kinematic machine (PKM) are coupled and averaged to be a final volumetric error.

4. Summary

In this paper, a novel 6-axis tool holder based on a Hexapod robot is developed for micro-cutting machines. In order to study the feasibility of the tool holder for metal cutting, the dynamic performances of Hexapod and machine slide are compared. It is found that although the Hexapod mechanisms induce new peaks in the PSD of thrust force, the amplitude of the vibration is insignificant in the thrust direction. Experimental results show that the surface roughness of the specimen machined by the proposed tool holder could attain the sub-micrometric level.



(a)



(b)

Figure 3. Power spectral density of the cutting forces

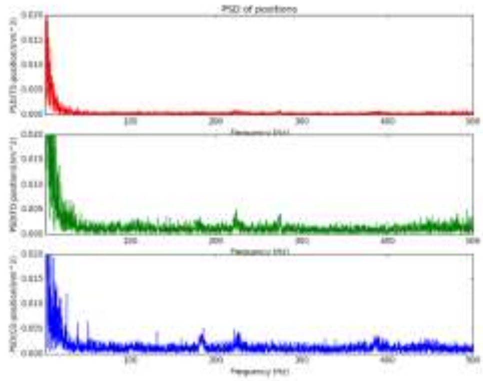


Figure 4. The PSD of position data of the moving platform

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