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Micro-topography generation method using a rotating tool actuated by an electromagnetic actuator

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Abstract

This paper presents a micro-patterning or surface texturing technique on the fixed work surface using a proposed new spindle system with a rotating cutting tool controlled by the electromagnetic actuator in real time. The proposed spindle system creates micro-sized patterns using rotating tools such as a micro-milling tool and a micro-grinding wheel. The shaft of the spindle is suspended by air bearings, and an electromagnetic actuator controls the radial motion of the spindle housing instead of the shaft. A PID controller is adopted to make the system stable, and adaptive feedforward cancellation is used to effectively compensate for the run-out of the spindle system during machining. The micro pattern array and the digital images are generated on the electro-less Ni coated workpiece using a single-flute diamond square end mill. The machining results show that the run-out compensation improves the machining accuracy. It is expected that micro-patterning using the proposed spindle system can be applied over a large surface area which is fixed at the work table.

KEYWORDS : Micro-patterning, Surface texturing, Rotating tool

1. Introduction [1]

The proposed spindle system with the electromagnetic actuator (EMA) can be applied to fabricate the micro-sized patterns on a large surface area. The EMA compensates the run-out and controls the radial motion of the shaft in real time. The structure is represented in Fig. 1. The EMA force acts directly on the shaft. The proposed spindle system has a structure in which the EMA actuates the spindle housing instead of the shaft.

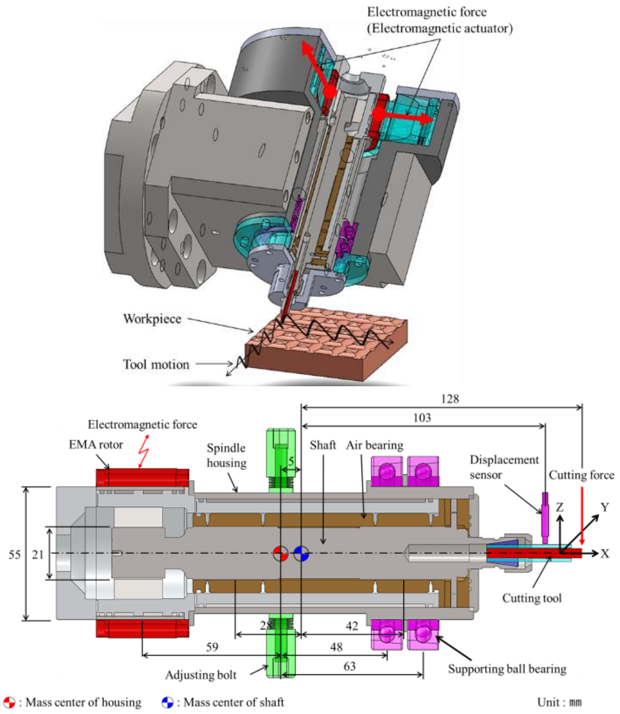


Figure 1. Structure of the proposed spindle system.

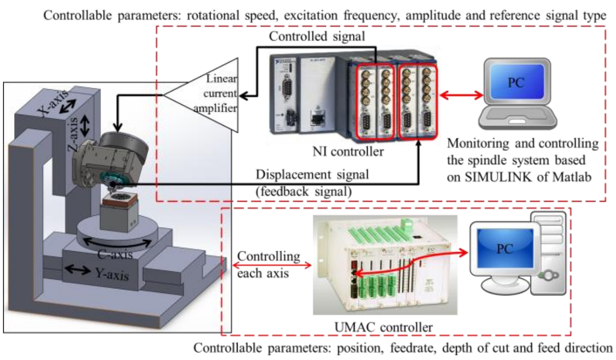


Figure 2. Machining system configuration.

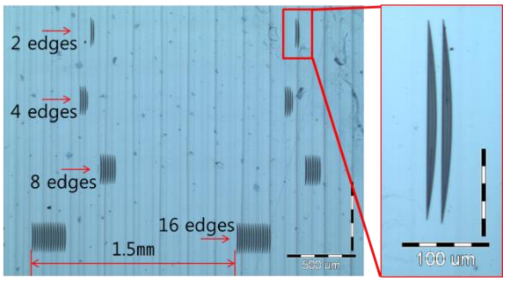
The spindle is installed on a 4-axis ultraprecision machine as shown in Fig. 2. A UMAC controller on a PC controls each axis, of which parameters are the position, federate, depth of cut and feed direction. An NI controller was used to monitor and control the spindle system based on SIMULINK, in which the rotational speed, excitation frequency, excitation amplitude and reference signal type. The controlled signal is transferred to the linear current amplifier, and the displacement signal is transferred to the NI controller.

2. Machining test results

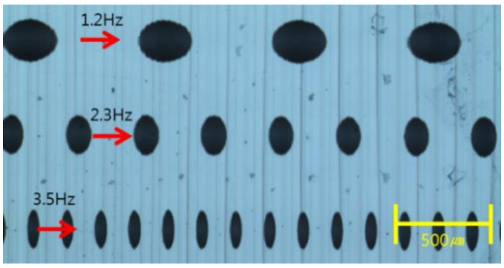
2.1. Micro-milling process [1]

A single-flute diamond square end mill with a diameter of 2mm was used for the micro-milling process. The workpiece is a Ni-coated STAVAX. Figure 3, 4 and 5 show the results according to the input reference signal and machining conditions.

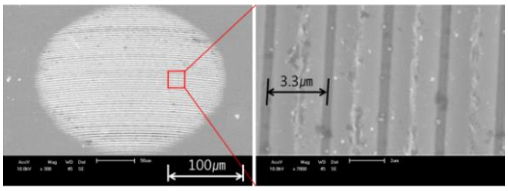
The hologram image which has the maximum depth as much as 3.6 μm and it consists of 256 levels from 0 to 255 in accordance with its information of grey scale of original image(Figure 5). Hence its theoretical minimal size of depth is 0.014 ㎛ which is the same as the accuracy of patterning.



(a) Scrapping pattern (feed per edge 16.7 ㎛ with square wave)



(b) Circular pocket (feed per edge 3.3 ㎛ with sine wave)



(c) Grating micro-dots (feed per edge 3.3 ㎛ with sine wave)

Figure 3. Micro-patterning by several reference signals.

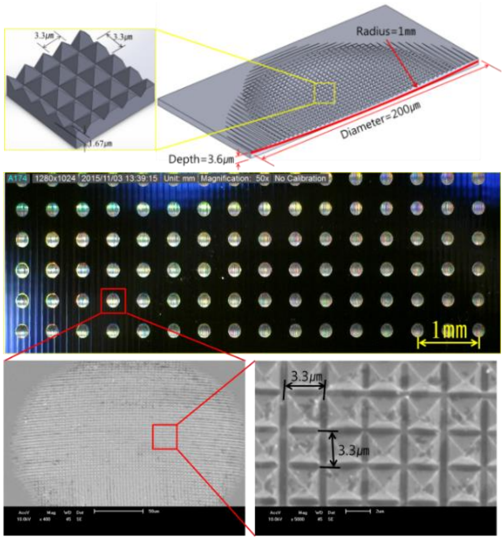


Figure 4. Micro-lens array with pyramid shape on the surface.

Original image Machined hologram image

Figure 5. Machined hologram image.

Figure 6 shows magnified surface of figure 5. As the reference input change, depth and size do well also.

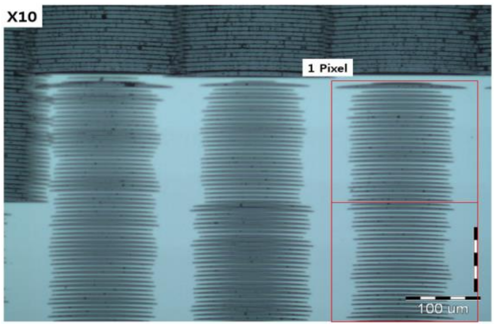


Figure 6. Magnified surface of machined hologram image.

2.2. Micro-grinding process

The 2mm diameter vitrified bond CBN wheel was used to machine the surface of hardened STAVAX. In order to make a micro-lens array, the excitation signal was given by a sine wave. The desired diameter of the micro-lens is 170 ㎛, and the desired height is 3.6 ㎛.

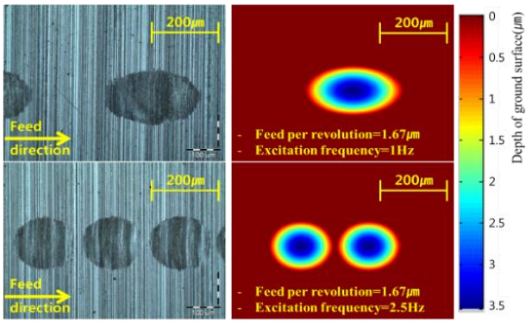


Figure 7. Ground surface according to the machining conditions.

3. Conclusion

The micro-milling test with a single-flute diamond square end mill and micro-grinding test with a vitrified bond CBN wheel were carried out with an inclination angle of 45 degrees. By choosing machining conditions, circular pockets, micro-lens array, and pyramid patterns were generated effectively on the micro-lensed surface. Moreover, it can generate the hologram image using the grey scale picture with patterning accuracy as much as 0.014 ㎛. It is expected the proposed spindle system can be applied to generate micro/nano-patterning and surface texturing in order to make various shapes on a large area.

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References

[1] J.H. Kim and S.-K. Lee 2016 Micro-patterning technique using a rotating cutting tool controlled by an electromagnetic actuator *I.J. Mach. Tools Manuf.* **101** 52-64