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Milling of wood and wood-based materials with a computerized numerically controlled router IV: development of automatic measurement system for cutting edge profile of throw-away type straight bit

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Abstract In industrial machining of timber, the method in which the operator visually inspects both wear and chippings of router bits after stopping the machine is generally adopted. However, many working hours are lost in this method and productivity suffers. Therefore, the development of a system that can automatically measure wear or chippings without stopping the machine is desirable. In this study, a laser measuring instrument was installed in a computerized numerically controlled (CNC) router, and an automatic measurement system for the cutting edge profile of throw-away-type straight bits with single-edged blades was developed. The main results are summarized as follows: (1) an automatic measurement system for the cutting edge profile of the bit was constructed; (2) this system was composed of a laser measuring instrument, a control personal computer (PC) for the CNC router, and a monitoring PC to control some devices and collect sampling data; (3) the system could measure the cutting edge profile of the bit without stopping the CNC router.

Key words CNC router · Laser measuring instrument · Automatic measurement system

Introduction

Computerized numerically controlled (CNC) woodworking machinery can automatically control the movements of a spindle and table. Recently, CNC woodworking machinery has been widely introduced in wood industries for automatically cutting, drilling, and shaping. A type of CNC router has become especially popular in furniture manufacturing, and has been used for the grooving, side milling, and patterning of furniture material. CNC routers have been introduced into the production lines of precutting factories, and have been used under demanding processing conditions with the aim of raising productivity. Therefore, tool wear progresses rapidly and chipping frequently occurs, which greatly influences productivity and product quality. The method in which the operator stops the machine and visually inspects the bit is generally used for confirming tool wear and chipping. However, this method consumes many working hours, causing productivity to suffer. Therefore, the development of a system that could automatically measure tool wear and chipping without stopping the machine is very desirable.

Thus, the authors investigated the most accurate grooving and side milling of wood and wood-based materials performed by a CNC router,[1,2] and determined the effects of tool wear on machining accuracy for grooving under various milling conditions.[3] In addition, a laser measuring instrument[4] was installed in a CNC router and a tool wear monitoring system was constructed. As a result, it became possible to automatically monitor progression of tool wear under processing conditions.[5] Moreover, many studies on tool wear monitoring have been conducted in the past.[6–13]

The purpose of the present study was to monitor the cutting edge automatically, and to develop a system for automatically measuring the cutting edge profile of the throw-away-type straight bit with single-edged blade. Verification experiments of this system were also carried out.

Materials and methods

Cutting tool and experimental apparatus

A throw-away-type straight bit with a single-edged blade having a cutting diameter of 10 mm was used (Fig. 1). The shape of the tip is shown in Fig. 2. The tip material was K05-

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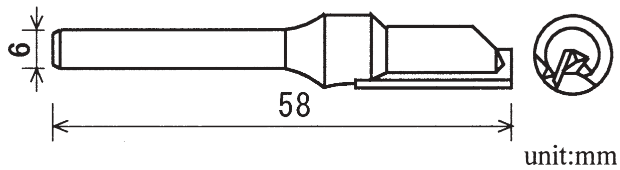

Fig. 1. Drawing of router bit

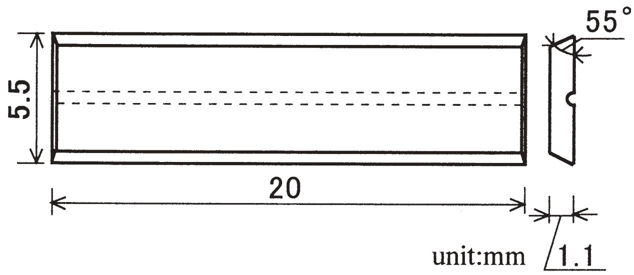

Fig. 2. Drawing of cemented carbide tip

Table 1. Specifications of laser measuring instrument

Parameter	Specification
Measuring range	0.2–40 mm
Light source	Semiconductor laser 670 nm
Accuracy	Less than ±2 μm
Repeatability	Less than ±0.3 μm
Scanning rate	121 m/s

grade cemented carbide and the edge angle was 55 degrees. The rake and clearance angles in the setting were 22 and 13 degrees, respectively.

A three-axis control CNC router (Karatsu Iron Works, RT-1 CNC Router) was used in this study. It has a maximum spindle speed of 400 rps, a maximum feed speed of 0.12 m/s, and a position accuracy of within 0.001 mm.

Measurement principle of the laser measuring instrument

Specifications for the laser measuring instrument (Keyence, LS-5500) are shown in Table 1. Figure 3 shows the principle governing this measurement method and the sensor head of the laser measuring instrument. This measuring instrument works via a mechanism in which the laser is scanned from Edge 1 to Edge 4 (Fig. 3) by a rotating polygon mirror and a light requirement device. The size of the object to be measured is calculated based on both the time in which the laser is intercepted by the object and the scanning rate. As shown in Fig. 3, when the idling router bit enters the measurement area, the maximum value for the outside diameter of the router bit (D_{max}) can be calculated based on the time between the laser's interception from Edge 2 to Edge 3. However, measurement using this instrument was not possible when the spindle speed was above 200 rps. Thus, it was necessary to lower the spindle speed. Preliminary experiments showed that stable measurements could be obtained when the spindle speed was set to 30 rps.

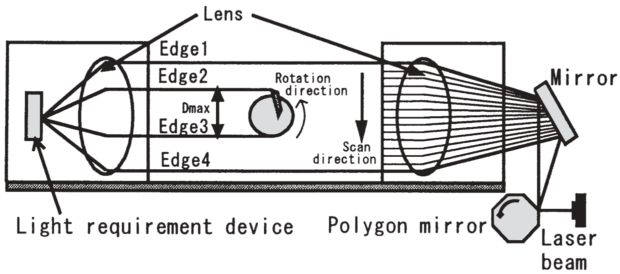

Fig. 3. Principle of the laser measuring instrument. D_{max}, maximum diameter of router bit

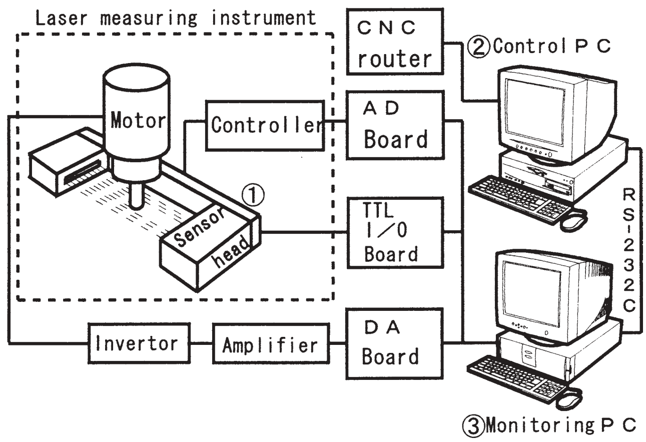

Fig. 4. Schematic diagram of automatic measurement system. ①, Laser measuring instrument; ②, control PC; ③, monitoring PC; *CNC*, computerized numerically controlled; *AD*, analog to digital conversion; TTL I/O, transistor-transistor logic I/O port; *DA*, digital to analog conversion

Outline of automatic measurement system

Figure 4 shows a schematic diagram of the system used to automatically measure the cutting edge profile of a bit. This system was composed of the laser measuring instrument, the control personal computer (PC) for the CNC router, and a monitoring PC to control certain devices and collect sampling data. When the idling bit enters the range of the sensor head of the laser measuring instrument, this system can automatically measure the bit outside diameter. However, as mentioned above, it was necessary to set the spindle speed to 30 rps for this measurement. Therefore, an invertor was installed in this system, thus allowing control of the spindle speed. A bit that was worn by 59 μm was used, the spindle speed was set to 30 rps, the sampling rate was set to 1000 Hz, the sampling frequency was set to 256, and the outside diameter of the bit was measured. The typical output signal obtained under these conditions is shown in Fig. 5. The waveforms seen in Fig. 5A describe the noncutting part of the router bit, while those of Fig. 5B describe the cutting part. The horizontal lines in Fig. 5 show the maximum value for the outside diameter of the noncutting and cutting parts as measured by hand after stopping the rotat-

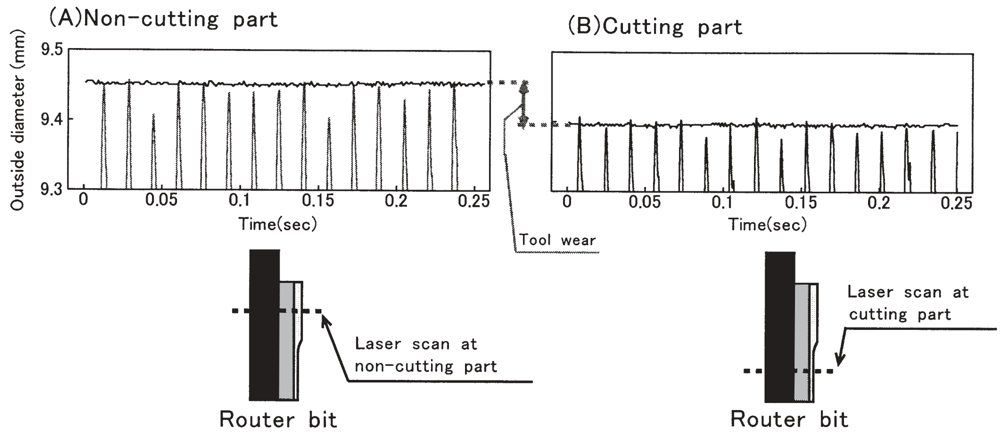

Fig. 5. Typical output signal of laser measuring instrument for **a** noncutting part and **b** cutting part

ing bit. From the results, the maximum values measured by the test system almost correspond to the value measured by hand. Therefore, it is clear that the system proposed is able to measure the outside diameters of the noncutting and cutting parts of the router bit.

Automatic measurement of the cutting edge profile

The automatic measurement program of this system was made using Visual Basic version 6.0. As the first step of the measurement procedure, the monitoring PC reduces the spindle speed to 30 rps after processing, and transmits the numerical controlled (NC) data for the movement of the bit to the control PC. As a result, the bit moves into the range of the sensor head positioned in a place away from the workpiece. The monitoring PC then samples analog data of the outside diameter that the laser measuring instrument outputs through the analog to digital conversion (AD) board. In addition, in order to remove variation in the measurements caused by diffused reflection of the laser and noise, the sampling data is permuted in descending order, and the mean value from the fifth to the ninth data is calculated. This value is used as a measurement value.

As the first step in measuring the cutting edge profile of the bit, the beginning-of-measurement position, the end-of-measurement position, and the measurement interval are established (Fig. 6). The bit is moved into the range of the sensor head so that the laser contacts the bit at the beginning-of-measurement position. The monitoring PC samples analog data regarding the outside diameter and calculates its maximum value. The bit is then raised to the set measurement interval, and the maximum value of the outside diameter is calculated again. This process is conducted repeatedly until the end-of-measurement position is reached, and the obtained values are plotted on the screen of the monitoring PC. The values are interpolated on a curve by a third function, and drawn on the screen as the cutting edge profile of the router bit (Fig. 7). Thus, the cutting edge profile of the router bit can be measured.

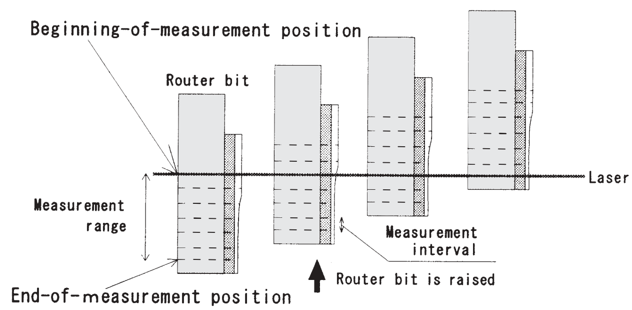

Fig. 6. Measurement of cutting edge profile

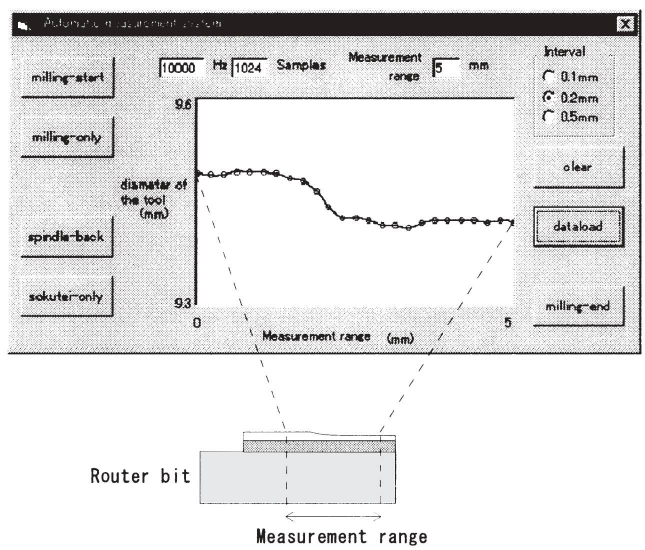

Fig. 7. Monitoring screen of the automatic measurement

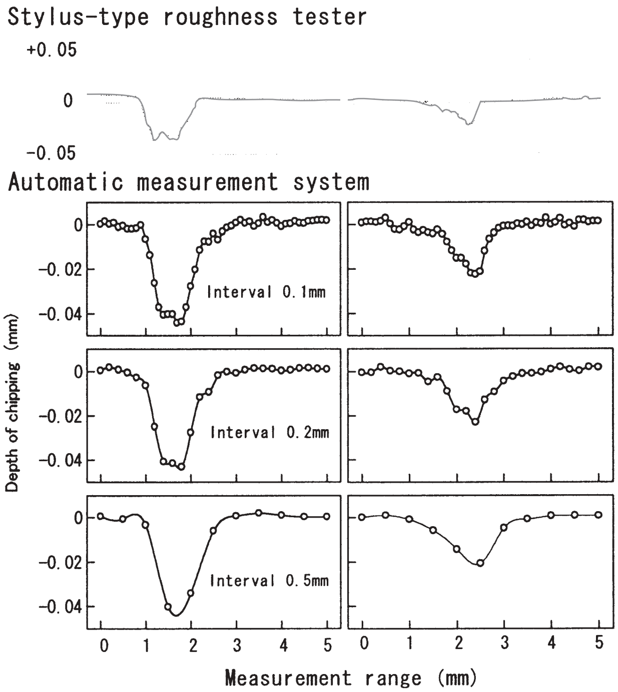

Fig. 8. Cutting edge profiles obtained by automatic measurement system and stylus-type roughness tester

Verification experiment results and discussion

Throw-away-type straight bits that experience large and small chipping were used. In measurements using this system, the sampling rate was set to 10kHz and the sampling frequency was set to 1024. The beginning-of-measurement position and the end-of-measurement positions were established, and the range of measurement was set to 5mm. The measurement system was tested at three different intervals (0.1, 0.2, and 0.5mm). In addition, the cutting edge profile of the rake face was obtained using a stylus-type roughness tester for comparison. Figure 8 shows the results obtained by both measurements. From these results, the cutting edge profiles in the case of 0.1-mm and 0.2-mm intervals were almost corresponding to the cutting edge profile obtained using a stylus-type roughness tester. Therefore, it was found that the proposed system could measure the cutting edge profile of a router bit. The measurement time was 46s when the measurement interval was 0.1mm, approximately 28s for the 0.2-mm intervals, and approximately 17s for the 0.5-mm intervals. Considering both measurement accuracy and measurement time, it is recommended that the measurement interval of this system be set at 0.2mm.

Conclusions

In this study, a laser measuring instrument was installed in a CNC router, and a system for automatically measuring the cutting edge profile of a bit was developed. The main results obtained are summarized as follows:

1. The described system for automatically measuring the cutting edge profile of a throw-away-type straight bit was composed of a laser measuring instrument, a control PC for the CNC router, and a monitoring PC for the control of certain devices and to collect sampling data.
2. It was found that the system could measure the cutting edge profile of the bit without stopping the CNC router.

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