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Development and Implementation of a Simplified Tool Measuring System

Jenn-Yih Chen[1], Bean-Yin Lee[2], Kuang-Chyi Lee[3], Zhao-Kai Chen[4]

[1,2]Department of Mechanical and Computer-Aided Engineering, National Formosa University
[3]Department of Automation Engineering, National Formosa University
[4]Institute of Mechanical and Electro-Mechanical Engineering, National Formosa University
64, Wunhua Rd., Huwei, Yunlin 632, Taiwan
[1]jychen@nfu.edu.tw, [2]leebyin@nfu.edu.tw, [3]kclee@nfu.edu.tw, [4]kai9in9in9in2002@yahoo.com.tw

This paper presents a simplified system for measuring geometric profiles of end mills. Firstly, a CCD camera was used to capture images of cutting tools. Then, an image acquisition card with the encoding function was adopted to convert the source of image into an USB port of a PC, and the image could be shown on a monitor. In addition, two linear scales were mounted on the X-Y table for positioning and measuring purposes. The signals of the linear scales were transmitted into a 4-axis quadrature encoder with 4-channel counter card for position monitoring. The C++ Builder was utilized for designing the user friendly human machine interface of the measuring system of tools. There is a cross line on the image of the interface to show a coordinate for the position measurement. Finally, a well-known tool measuring and inspection machine was employed for the measuring standard. This study compares the difference of the measuring results by using the machine and the proposed system. Experimental results show that the percentage of measuring error is acceptable for some geometric parameters of the square or ball nose end mills. Therefore, the results demonstrate the effectiveness of the presented approach.

Keywords: Tool measuring system, geometric profile, human machine interface (HMI)

1. Introduction

THE DEMAND for all kinds of high precision cutting tools relatively increases owing to rapid developments in the modern cutting technology and materials [1, 2]. The grinding for cutting edges of tools is known as the most important and the final manufacturing procedure. It is also a critical issue for determining geometry shapes, cutting performance, wear on cutting edges, and tool life. The precision and accuracy of tools often result from grinding. If tool measuring and inspection machines can accurately measure the geometric profiles, this leads to quality improvement of tools for cutting tool manufacturers.

In order to match up to the tool precision requirements, the digital image processing technology is widely adopted for measuring the micro-size of workpieces in industrial applications. Because of its practical importance, much research has been done concerning the tool measurements via the digital image processing. Reference [3] proposed a stereometric imaging method to measure the depth of profile, and employed artificial neural network for tool wear estimation. A reliable scheme for the reduction of error components was suggested by using a CCD camera and an exclusive jig to be able to precisely measure the size of tool wear [4]. Afterwards, [5, 6] also presented the tool wear or the flank wear measuring techniques based on the machine vision system. Hazra et al. adopted silhouette image processing to develop a simple inspection system for drill point geometry [7]. The system can measure five geometric parameters of drills, and it has more precision than human operators with a microscope.

Although many studies have been done on tool machining or wear measurements, few studies have reported on the design, grinding, and dimensional inspection combined with the digital image processing for end mills. Currently, more detailed and useful know-how of milling cutters is in the possession of a few famous companies, and it is difficult to acquire. Hence, this paper is aimed at designing a tool inspection machine and developing a measuring system. The present method is easy to apply and useful due to its simplicity.

2. Measuring Methods of Tool Geometry

Fig.1 shows how to measure the diameter of an end mill. Let the cross line approach the points P_1 and P_2 on the outside contour of the end mill. The diameter D can be obtained by utilizing the formula $D = \overline{P_1P_2} = |Y_2 - Y_1|$. Another scheme employs the points P_3 and P_4 to form a line segment, and then calculates the perpendicular distance from P_5 to the line to get the diameter.

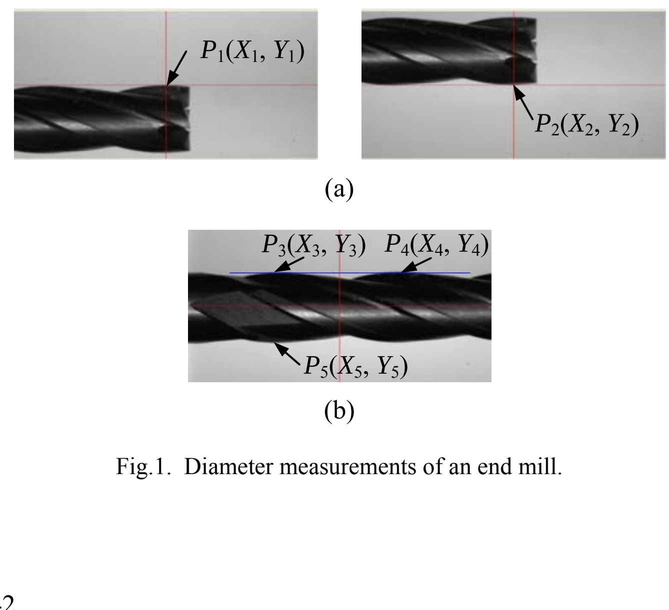
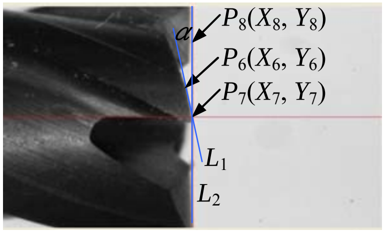


Fig.1. Diameter measurements of an end mill.

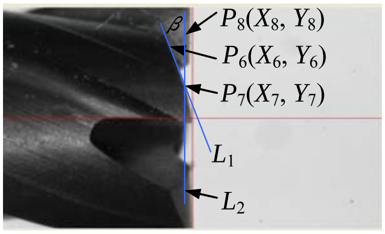
The measuring approach for obtaining the axial relief angle and the clearance angle of end mills is shown in Figs. 2(a) and 2(b), respectively. Let the points P_6 and P_7 lie on the relief surface or the clearance surface. Two lines L_1 and L_2 can be expressed as $L_1 : a_1 x + b_1 y + c_1 = 0$ and $L_2 : a_2 x + b_2 y + c_2 = 0$, respectively. The coordinates of P_6 and P_7, and P_7 and P_8 are substituted into the equations of L_1 and L_2 to solve the constants a_1 and b_1, and a_2 and b_2, respectively. Thus, the axial relief angle α between L_1 and L_2 is governed by the relation

$$\alpha = \cos^{-1}\left(\left(a_1 a_2 + b_1 b_2\right) \Big/ \left(\sqrt{a_1^2 + b_1^2}\,\sqrt{a_2^2 + b_2^2} \right) \right).$$

The measuring method and the calculation of the axial clearance angle β are similar to the axial relief angle.



(a)



(b)

Fig.2. Schematic diagrams for measuring angles: (a) axial relief angle measurement; (b) axial clearance angle measurement.

Fig.3 displays a helix angle measuring scheme. One measures the diameter D of an end mill as pointed out above at first. Let the point P_9 lie on the spiral line, and further let the end mill rotate g degrees to make another point P_{10}, which also lies on the spiral line. The spiral pitch h is $\left|X_{10} - X_9\right|$. Hence, the helix angle θ can be expressed as $\theta = \tan^{-1}\left(g\pi D/(360h) \right)$.

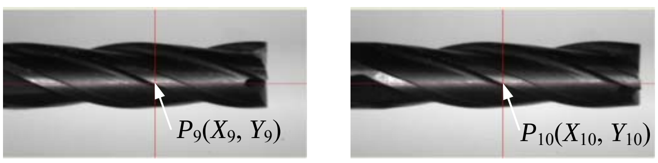


Fig.3. Helix angle measurement of an end mill.

Let these points P_{11}, P_{12}, and P_{13} approach the profile of an end mill. A line segment is formed with P_{11} and P_{12}, and then its perpendicular bisector is found. Similarly, using P_{12} and P_{13}, we obtain another perpendicular bisector. The cross point of these two perpendicular bisectors is the center point. Therefore, the radius of ball nose or radius end mills is from this center point to P_{11}, P_{12}, or P_{13}. The measuring method of the radius is shown in Fig.4.

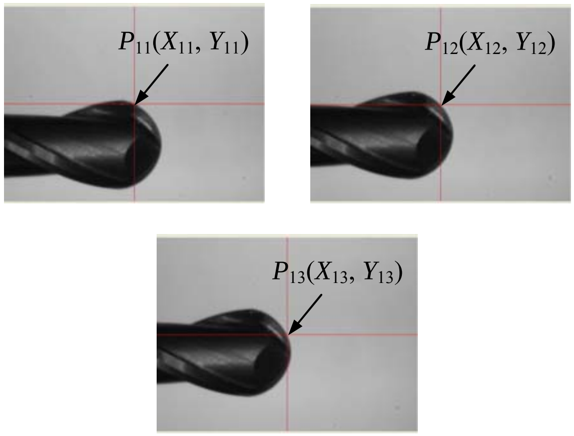


Fig.4. Radius measurement of ball nose or radius end mills.

3. DESIGN OF HMI FOR TOOL MEASUREMENTS

Fig.5 shows the proposed HMI for tool measurements. It was designed by the C++ Builder. The HMI has five functions as mentioned in Section 2, and the measuring functions and the result are shown on the lower left side and the upper right side, respectively. The linear scale measurement mode adopted the signals of linear scales, which are mounted on the X-Y table to measure geometric parameters of cutting tools. These parameters can be obtained by some coordinates of the central point of the cross line. However, the image pixel measurement mode employed a CCD camera to capture static images of tool profiles. One can use a mouse to click some points on an image with 640×480 pixels. One pixel is equal to 0.0139 mm in this paper. The HMI then converted the pixel into the practical displacement for calculating the parameters of tools. The image pixel measurement mode doesn't measure a helix angle and due to this it cannot dynamically capture images. The flowchart of the measuring process is shown in Fig.6.

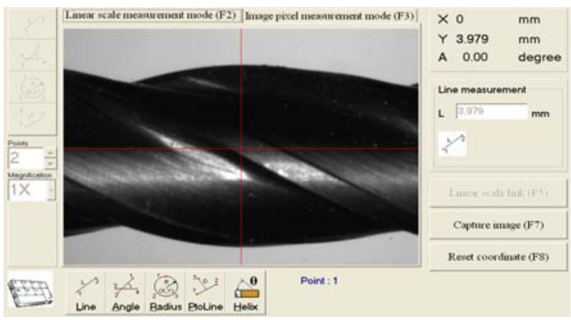


Fig.5. Designed Human machine interface.

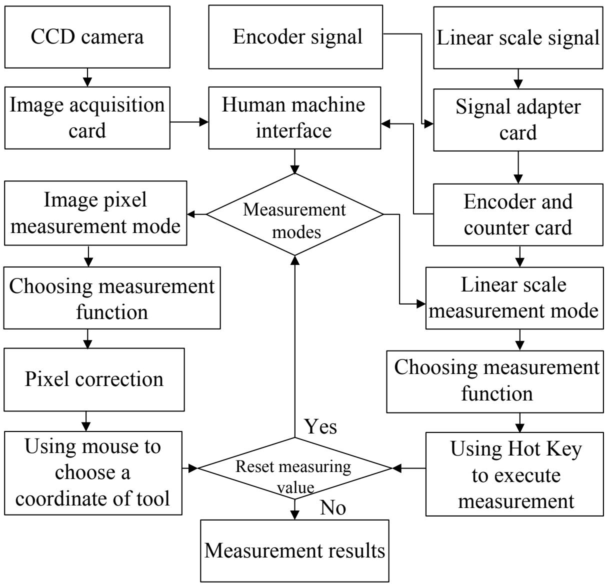


Fig.6. Flowchart of the measuring process.

4. Experimental Results and Analysis

Figure 7 illustrates the prototype measuring instrument. It combines with the machine vision and digital image processing technology for measuring basic geometry shapes of cutting tools. The experimental set up consists of a PC, a CCD camera with three hundred thousand pixels for capturing images of tools, a chuck with BT shank, two linear scales with 1μm resolution for measuring the displacement of the X-Y table, and a rotary encoder with 3600 ppr. The main purpose of this encoder is utilized for measuring the rotation degree of tools, and its accuracy is improved by the four times frequency multiplier.

A well-known tool measuring and inspection machine has the display accuracy 1 μm, positioning accuracy ± 1 μm, repeatability ± 2μm, and concentricity 2μm. Its measurement results are considered as the standard in this paper. Tables 1-5 contain a comparison between the measurement results of presented measurement modes and those measured by adopting the tool measuring and inspection machine. Each measuring experiment was repeated five times. For the linear scale measurement mode, it is obvious that the maximal percentage errors are 4.38% and 2.3% for the angle and the dimensional measurements, respectively. However, the image pixel measurement mode has 5.79% and 4% percentage errors for the angle and the dimensional measurements, respectively. Owing to this, one is unable to click a suitable position of geometric profiles of an end mill or the lower resolution of a CCD camera. Thus, this leads to the higher error than using the linear scale measurement mode.

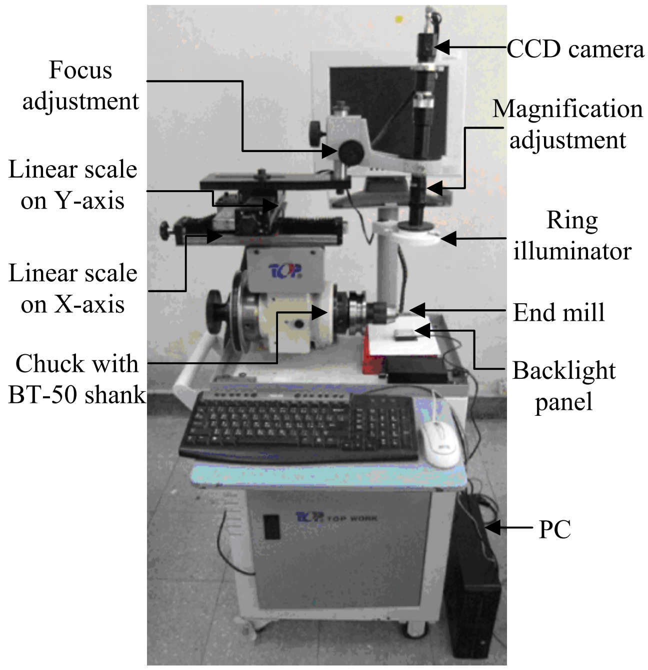


Fig.7. Photograph of the measuring instrument.

Tab.1. Measurement results of a square end mill with 4 mm diameter by using different measurement modes.

Exp. no.	Tool measuring and inspection machine		Linear scale measurement mode			Image pixel measurement mode		
	Measuring value (mm)	Average value (mm)	Measuring value (mm)	Average value (mm)	Error	Measuring value (mm)	Average value (mm)	Error
1	3.987	3.988	3.979	3.986	3.988−3.986 = 0.002 mm 0.002/3.988 = 0.05 %	3.959	3.976	3.988−3.976 = 0.012 mm 0.012/3.988 = 0.3 %
2	3.988		3.988			3.986		
3	3.989		3.987			3.979		
4	3.987		3.984			3.981		
5	3.988		3.991			3.973		

Tab.2. Measurement results of a square end mill with 7° axial relief angle by using different measurement modes.

	Tool measuring and inspection machine		Linear scale measurement mode			Image pixel measurement mode		
Exp. no.	Measuring value	Average value	Measuring value	Average value	Error	Measuring value	Average value	Error
1	7.01°	7.08°	6.99°	7.39°	7.39° − 7.08° = 0.31° 0.31°/7.08° = 4.38 %	7.59°	7.49°	7.49° − 7.08° = 0.41° 0.41°/7.08° = 5.79 %
2	7.25°		7.57°			7.35°		
3	7.08°		7.59°			7.12°		
4	6.96°		7.12°			7.97°		
5	7.11°		7.69°			7.43°		

Tab.3. Measurement results of a square end mill with 16° axial clearance angle by using different measurement modes.

	Tool measuring and inspection machine		Linear scale measurement mode			Image pixel measurement mode		
Exp. no.	Measuring value	Average value	Measuring value	Average value	Error	Measuring value	Average value	Error
1	15.86°	15.85°	15.74°	15.7°	15.85° − 15.7° = 0.15° 0.15°/15.85° = 0.95 %	16.14°	15.48°	15.85° − 15.48° = 0.37° 0.37°/15.85° = 2.33 %
2	16.01°		15.50°			15.43°		
3	15.71°		15.48°			15.64°		
4	15.88°		15.94°			15.12°		
5	15.78°		15.84°			15.07°		

Tab.4. Measurement results of a square end mill with 35° helix angle by using linear scale measurement mode.

	Tool measuring and inspection machine		Linear scale measurement mode		
Exp. no.	Measuring value	Average value	Measuring value	Average value	Error
1	34.78°	34.79°	34.49°	34.34°	34.79° − 34.34° = 0.45° 0.45°/34.79° = 1.29 %
2	34.92°		34.38°		
3	34.67°		33.99°		
4	34.81°		34.03°		
5	34.79°		34.80°		

Tab.5. Measurement results of a ball nose end mill with 3 mm radius by using different measurement modes.

	Tool measuring and inspection machine		Linear scale measurement mode			Image pixel measurement mode		
Exp. no.	Measuring value (mm)	Average value (mm)	Measuring value (mm)	Average value (mm)	Error	Measuring value (mm)	Average value (mm)	Error
1	2.999	2.998	2.978	3.067	3.067 − 2.998 = 0.069 mm 0.069/2.998 = 2.3 %	3.092	3.118	3.118 − 2.998 = 0.12 mm 0.12/2.998 = 4 %
2	2.998		3.174			3.235		
3	2.997		3.139			2.951		
4	2.999		3.083			3.152		
5	2.996		2.959			3.162		

5. CONCLUSIONS

A simplified measuring system for the geometric parameters of end mills has been developed in this paper. The experimental results show that the linear scale measurement mode has higher accuracy than the image pixel measurement mode. The advantages of the proposed system are low-priced and efficiency. Furthermore, the designed measuring instrument and the HMI may apply to measuring geometric profiles of different cutting tools.

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