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Tool wear measurement of ball-end cutter based on shape mapping

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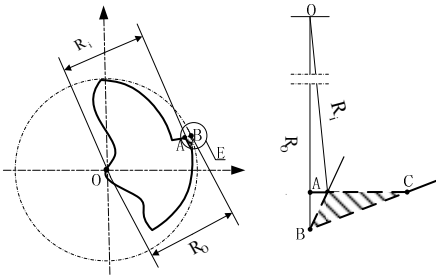
Abstract. In milling process, tool wear has important influence on product machining quality. A measuring method for tool wear of ball-end cutter is proposed in order to predict effectively tool wear. The measuring method maps tool wear shape on a block of metal material by milling hole mode after finishing each milling experiment. These formed holes are measured on CMM (coordinate measure machine) by using the planned measuring method. The measuring process is established to attain tool wear of ball-end cutter. The experiments results show that the proposed measuring method can effectively attain tool wear to provide a foundation for tool wear modeling and monitoring.

Introduction

Tool wear monitoring has been widely investigated research topic. Tool wear monitoring is of two types: direct and indirect. Direct methods measure the actual values of size of wear parameters with optical instruments, while indirect methods measure parameters such as cutting forces or vibrations that are correlated with tool wear. In direct measuring method, Mannan M.A.et al[1] sets the energy of various sub-map into the characteristic vector of neural network by using tree-based wavelet transform method for achieving both tool wear image segmentation. Kassitn A.A.et al[2] used fractal texture of the surface characteristics of workpiece images, and successfully describes the complexity of texture. Kuljanic.E et al[3] applied the AR spectrum based on wavelet packet (WP-AR) analysis method on tool wear monitoring. Myshkin N.K et al[4] extract the edge characteristics of the workpiece image by using fast Hough transform and experiments show that the method has higher accuracy compared to the traditional Hough transform. In indirect measuring method, Wang Haiti [5] takes the different characteristics of the cutting force signals using a neural network mapping tool wear and cutting force relationship. Reference [6-8] studied the cutting force during the cutting process by using the cutter geometry model and established the cutting experience model. The tool wear can be attained by designed machining experiments. The variable law of the cutting force was searched to achieve tool wear prediction or monitoring purpose. The paper proposed a tool wear measuring method based on shape mapping in order to efficiently control the tool wear of the machining process.

Theory Foundation of Shape Mapping

The Principle of Shape Mapping. In milling process, the cutter radius on the worn areas will change with the increase of tool wear. That is to say, the cutter radius on the worn areas can reflect the tool wear state. So we can utilize this characteristic to retain tool wear information on a metal material, which has low influence on tool wear, by using milling hole mode or other ways. This provides foundation for shape mapping of the worn cutters. The description for shape mapping of the worn cutters can be shown as Fig.1, which is a relation schematic between tool wear and cutter radius on the worn areas. Fig.1 (a) is a main diagram and Fig.1 (b) is a detail diagram. In Fig.1, R_o is the unworn cutter radius and R_i is the worn cutter radius. Area ΔABC is cutter wear areas and edge AC is the cutter flank wear extent. Fig.1 shows that the cutter radius on the worn areas varies with the flank wear extent and can retain tool wear information by means of shape mapping.



(a) Main diagram (b) Detail diagram of *E*

Fig. 1 Relation between tool wear and cutter radius

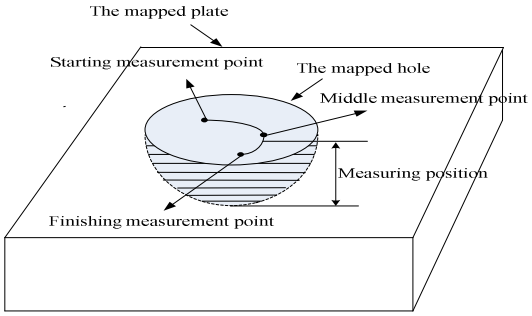


Fig.2 Measuring process of tool wear

Tool Wear Measuring Method Based on Shape Mapping

Shape Mapping of Tool Wear. First, a group of machining experiments is designed according to the cutter material and workpiece material. And then start machining with a new milling cutter and map the initial cutter shape into the mapped plate before machining experiments. After each experiment, the cutter is worn and then the worn cutter is used to mill a hole on the mapped plate.

Determination of Measuring Position. After shape-mapping process of tool wear is completed, we need to dispose the mapped holes shape on the mapped plate, which is different for the reproduction from different type of cutter. Because the feed distance is equal to the experimental cutter radius in the shape mapping process the mapped holes from the same group of machining experiment have the same depth from the upper finished face of the mapped plate. This will ensure the same measurement position for different mapped holes. In order to measure the mapped holes, a series of positions are acquires along its axis line by dividing its axis. These positions can be identified as the measurement positions.

Measuring method of the Mapping holes. The same measuring position difference of each two mapped holes reflects tool wear state after attaining measuring position. And then the same position between the reference mapped hole and the worn mapped holes is compared to get the tool wear state of each machining condition in a group of machining experiment. These compare results form a series of differences. These differences are called the radial wear. We can see that the cutter and mapping plate in the shape mapping process do not be dismantled by analyzing the shape mapping process. Therefore their axes of different mapping holes for the same cutter are parallel to each other. The measuring method is proposed to dispose the mapping holes for the tool wear:

(1) First, four points around the mapping plate are selected to measure their coordinates by using the CMM and a plane is determined according to the coordinates of the selected four points.

(2) The eight points of cylinder surface on the reference mapping hole of each cutter are selected to determine the z axis of the measuring coordinate.

(3) A measuring position should firstly be given after determining the measuring coordinate. Then three measuring points of the mapping hole surface are selected at the given measuring position, that is the starting measurement point, the middle measurement point and the finishing measurement point. And the pre-prepared automatic measurement procedures are conducted to measure the points which are in range from the selected starting measurement points to the selected finishing measurement points and are along the direction determined by the given three measurement points. Measuring process of tool wear for ball-end cutter is shown as Fig.2.

(4)When all mapping holes at a measuring position for a cutter have been finished, the next measuring position is selected and conducted measuring process in accordance with the above steps. The measuring process can be ended until the required positions of the mapping holes have been finished the measurement.

(5) These measuring points' data from the same position are fitted to attain the section circle radius at the measuring position.

(6) The difference between the section circle radii of the adjacent mapping holes can be used to identify the tool wear status of ball-end cutter.

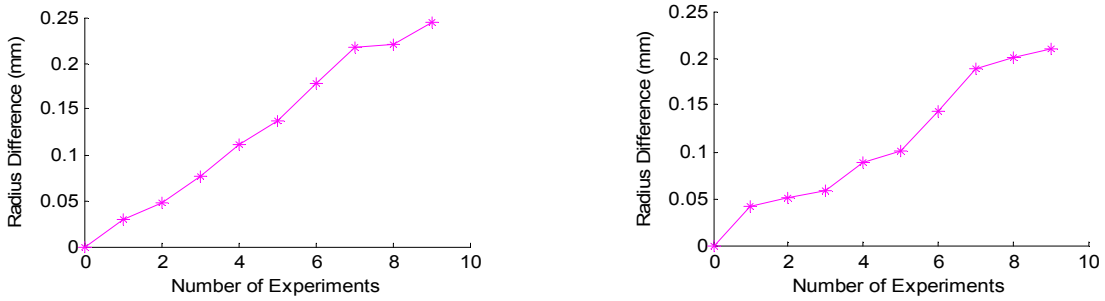
Experimental Verification

Experiments Setup. In order to verify the validity and reliability of the proposed tool wear measuring method, a series of milling wear experiments have been conducted on MIKRON UCP710 five-axis milling machining center. Stainless steel 1Cr18Ni9Ti, which is a difficult-to-cut material, is selected as work material of tool wear machining experiments. Aluminum alloy 6061 is selected as the mapped plate material compared to stainless steel 1Cr18Ni9Ti. Cemented carbides ball-end cutters are selected to conduct tool wear machining experiments. Cutter diameter, depth of cut, feed rate, spindle speed and cut length are suitably selected and given in Table.1.

Table.1 Orthogonal experiment parameters of ball-end cutter

Experiment Number	Cutting Depth a_p (mm)	Feed Rate f(mm/min)	Spindle Speed n(r/min)	Cutting Length L(mm)	Diameter D (mm)
1	1.2	150	1000	576	16
2	1.2	100	1400	504	16
3	1.2	120	1200	432	16
4	1.5	150	1200	504	16
5	1.5	100	1000	432	16
6	1.5	120	1400	576	16
7	1.8	150	1400	432	16
8	1.8	100	1200	576	16
9	1.8	120	1000	504	16

Experimental Steps. The shape mapping process of tool wear is the following according to the machining parameters of Table.1. Firstly, the machining material and the mapping material are mounted on the same worktable of machine tool. Secondly, diameter 16mm cemented carbides ball-end cutter is selected to conduct nine sets of experiments such as Table.1 of experiment number 1 to experiment number 9. The new cutter head shape before machining experiments is mapped into the finished aluminum alloy 6061 mapped plate along the machine tool spindle axis to feed 8mm by using milling mode. This forms a reference-mapped hole for diameter 16mm cemented carbides ball-end cutter on the mapped plate. Then the stainless steel 1Cr18Ni9Ti workpiece is milled according to machining parameter of Table.1 of experiment number 1. The worn cutter head shape is mapped into the finished aluminum alloy 6061 mapped plate along the machine tool spindle axis to feed 8mm by using milling mode after machining experiment. This will also forms another mapped hole as called worn hole. The rest Table.1 of experiment number 2 to experiment number 9 may be carried out such as experiment number 1. There should be ten mapped holes on the mapped plate including the reference hole after nine sets of machining experiments. Thirdly, the mapping holes of ball-end cutter are measured according to the proposed measuring method.



(a) Radius difference values at 0.8 mm depth (b) Radius difference values at 1.0 mm depth

Fig. 3 Radius difference values for the first sets of milling experiments

Experimental Results and Discussion.

Fig.3 gives the radius variation of the two depths for the first group of nine milling experiments using the diameter 16 mm cutters. Fig.3 (a) and Fig.3 (b) is radius variation for different depth position of diameter 16 mm cutters. We can see from the data of Table.2 that the tool wear data is basically meet tool wear law and the tool wear measuring method can be used in the following tool wear modeling.

Conclusions

In milling machining process, tool wear has important influence on product machining quality.This paper investigated the tool wear measurement method based on shape mapping from theoretically and experimentally aspects in milling process. The following is a summary of findings from the present work:

- A tool wear measuring method based on shape mapping for ball-end cutter has been established to dispose the mapping holes.
- The initial experimental work has demonstrated that the proposed tool wear measuring method can be used successfully in a measurement process of flank wear estimation. Experiments also show that a mapped tool wear processing strategy can allows for effective assessment of tool wear.
- The proposed tool wear measuring method does not acquire to stop the machining process. This can increase machine tool efficiency of tool wear machining experiments and provide an efficient way to acquire tool wear.

Acknowledgements

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